AD-A047 645 PATTERN ANALYSIS AND RECOGNITION CORP ROME N Y F/G 6/4
PERSONAL ATTRIBUTES AUTHENTICATION TECHNIQUES. (U)
OCT 77 G E FORSEN, M R NELSON, R J STARON F30602-76-C-0368
UNCLASSIFIED PAR-77-21 RADC-TR-77-333 NL

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RADC-TR-77-333
Final Technical Report
October 1977

PERSONAL ATTRIBUTES AUTHENTICATION TECHNIQUES

Pattern Analysis & Recognition Corporation

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ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: RADC-TR-77-333 (18) (19)

2. GOVT ACCESSION NO.:

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): (6) PERSONAL ATTRIBUTES AUTHENTICATION TECHNIQUES.

5. TYPE OF REPORT & PERIOD COVERED: (9) Final Technical Rep[redacted]t.

6. PERFORMING ORG. REPORT NUMBER: (14) PAR [redacted]-77-21

7. AUTHOR(s): (10)
Mr. George E./Forsen
Dr. Mark R./Nelson
Mr. Raymond J./Staron, Jr.

8. CONTRACT OR GRANT NUMBER(s): (15) F30602-76-C-0368 new

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Pattern Analysis and Recognition Corporation
228 Liberty Plaza
Rome, New York 13440

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
P.E. 62702F
J.O. 40270512

11. CONTROLLING OFFICE NAME AND ADDRESS:
Rome Air Development Center (IRAD)
Griffiss AFB NY 13441

12. REPORT DATE: (11) Oct[redacted]977

13. NUMBER OF PAGES: 326 (12) 331p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Same

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A

16. DISTRIBUTION STATEMENT (of this Report):
Approved for public release; distribution unlimited.

390 101

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
Same (16) 4027 (17) 05

18. SUPPLEMENTARY NOTES:
Project Engineer: Dr. Bruno Beek (IRAD)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
identity verification
C-trace
voice recognition

This research sought

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):
The purpose of this research was to isolate physiological attributes which would be of ~~utility~~ most in automatic identity verification for access control. The work proceeded in three stages. During the initial phase, over thirty (30) potential physical attributes were evaluated through mathematical modeling, opinion survey, and system analysis. The two best attributes, handprints and a modified electrocardiogram ~~we have~~ called a "C-trace", were selected for in-depth study. Data on both attributes was collected on seventy-two (72) subjects at three (3) sessions over three months during the second (2nd) phase. In the third (3rd) phase, → cont on P 1473B

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the data was analyzed to determine the Type I and II error rates for identity verification. A Type I error is a failure to recognize a legitimate subject, whereas a Type II error occurs when an imposter is identified as a legitimate subject. Results were quite encouraging. The handprint achieved a Type I error of 1.4 ~~percent~~ and a Type II of 1.6 ~~percent~~. The C-trace performed at a Type I of 1.2 ~~percent~~ and a Type II of 1.1 ~~percent~~. Arguments which indicate that the handprint results can be improved significantly and the C-trace moderately are given.

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EVALUATION

This exploratory development program investigated in detail those personal attributes which offer a potential to automatic identity of an individual for access control functions. The initial phases of this program were to find physical attributes that were unique to an individual and could be effectively automated with today's technology. This program was a natural outgrowth of RADC's successful automatic Speaker Verification System for access control and RADC's expertise in signal processing systems such as OLPARS.

Of the over thirty attributes studied, two were selected for detailed, in depth experimental investigation. Both of the attributes were found to meet existing entry control specifications. Hence, it is recommended that continued support be given in the operational realization of these attributes for future generation entry control systems.

Bruno Beek

BRUNO BEEK
Project Engineer

SECTION 1

INTRODUCTION

1.1. EXECUTIVE SUMMARY

From the aboriginal native who covers his body with tribal and individual tattoos to the astronaut disembarking at a space station to register in a voice recognition booth in 2001, A Space Odyssey, man has sought, in fact or in fiction, the means to identify individual members of his race. Arthur Clarke's vision of the future in 2001 is, like much of the better science fiction, based on fact. The technology necessary for automatic voice recognition has been pursued for some time and is currently the personal identity mechanism which is to be incorporated into the Air Force Base and Installation Security System (BISS). A speaker verification system has been developed by Texas Instruments which is able to meet the lowest level of BISS specifications, error rates near one per cent.

The Rome Air Development Center (RADC) has sponsored a considerable portion of the speaker verification work. Recently, however, this agency has begun to consider alternative means of identity verification and has, as a result, funded a modest investigation by Pattern Analysis and Recognition Corporation (PAR). This document constitutes a final report on the effort, Contract #F30602-76-C-0368.

There are many reasons for pursuing alternate means of identity verification. First of all, the one per cent error rate is only the lowest level of BISS specifications. At the highest level of security, one would like to achieve error rates as low as one part in a million. It is by no means certain that voice recognition can attain this goal. One hope is that some new attribute might meet the more stringent specifications. Additionally, there is always the possibility that smaller error rates can be gained by combining speaker recognition with some other attribute, one perhaps to emerge from the PAR investigation. Another motive for seeking additional means of identity verification is that voice recognition may not always be the best technology for every application. It may sometimes be too costly, or too slow, or, perhaps, too difficult to use.

Let us digress for a moment to make more precise two ideas which we have so far been using interchangeably, "identification" and "verification." Identification is to label an unknown individual of a population, whereas verification is to ascertain whether a labeled individual of a population is correctly labeled. Identification is the domain of forensics. Verification is what is demanded in most security systems for access control. Thus, an individual presenting himself for entry is assumed to cue the system by entering his name or code. The system simply verifies that the personal attribute being measured for that person agrees with the value already on file. The verification problem is obviously simpler, since any system which can perform identification can, *a fortiori*, perform verification.

A variety of means of identity verification alternatives to voice recognition are already under commercial development. Those known to the authors include fingerlength measurement by Identimat Corp., fingerprint recognition by Calspan Corp., body vibration transfer function by Novar Electronics Corp., signature recognition by Veripen Corp., and face recognition by a variety of investigators. PAR was excluded from examining fingerprints, face recognition, signatures, or retinal vein patterns.

PAR undertook three tasks for RADC. First, we were to perform a general study of alternate means of identification. From a list of candidate personal attributes, we were to single out two especially promising techniques for in-depth investigation. For the two personal attributes selected under the first task, PAR was to collect data on 72 people at three sessions over a period of three months. The final task was to use this data to determine the error rates for each of the two attributes.

The attributes listed in Table 1-1 were selected by PAR for evaluation. Sources for these attributes included RADC suggestions, books on forensics, medical and physiological literature, and the imagination of the staff.

The various physical attributes were evaluated for utility in a verification system by assigning numerical ratings to them in six categories. The categories for evaluation are listed in Table 1-2. "Separability" means the error rate of the technique. For verification systems, the errors are labeled Type I, a "sin of omission," the probability that a legitimate applicant will

Table 1-1 Personal Attributes Considered For Identification

1. Palm print (lines and/or ridges) and footprints
2. Finger folds
3. Finger lengths, hand area
4. Skin color, hair color, eye color
5. Vein pattern
6. Photoplethysmogram
7. Skin resistance
8. Total (body) resistance
9. Bone pattern (ultrasound)
10. Finger tremor pattern
11. IR radiation pattern
12. Eye scan path/dilation
13. Sonic characteristics of the teeth/skull
14. Bite patterns/fillings
15. Ear structure
16. Electroencephalograms
17. Visually evoked potentials of the brain
18. Visually evoked magnetic fields of the brain
19. Saliva
20. Blood composition
21. Odor/sweat
22. Height/weight

23. Gait

24. Electrocardiogram (ECG, DCG, Echocardiogram)

25. Ballistocardiogram

26. Verbal response pattern

27. Personal history

28. Typing style

29. Lip grooves

30. Polygraph

31. Implanted marks

32. Body vibration transfer function

33. Nail grooves

Table 1-1 (Continued)

Table 1-2 Evaluation Criteria for Personal Attributes

1.	Separability	-	Type I and II Error performance
2.	Acceptability	-	User acceptance
3.	Feasibility	-	Technological risk
4.	Cost	-	Development, production and operating
5.	Speed	-	Time for user to gain access
6.	Penetrability	-	Ease of access by a trained agent

Table 1-3 Error Rates

	Handprint	C-Trace
I	.014	.0122
II	.0164	.0107

be rejected by the system, and Type II, a "sin of commission," the probability that an illegitimate applicant will be accepted. The latter is assumed to be only a casual intruder and not a trained agent. To evaluate Type I and II errors theoretical formulas were derived which gave these errors as a function of standard deviations of the measured attributes for individuals and for the population at large. Acceptability was measured by circulating a questionnaire designed by PAR psychologists. The last four categories were evaluated by engineering investigations of verification systems based on the respective attributes. "Penetrability" was taken to mean ease of access by a determined intruder with knowledge of the detailed operation of the system.

The six categories were weighted, separability and acceptability being most important, penetrability being the least, and the scores were combined to attain an overall ranking for each attribute. Some judgment was required since it was not always possible to assign numerical scores to the attributes.

Two attributes were selected for detailed investigation: first, flexion crease lines on the palm and fingers, and second, electrocardiograms. Crease lines on the palms, those lines used by chiromancers, are congenital flexure lines and are located where the outer layers of the skin are more firmly attached to the subcutaneous tissue. In choosing crease lines, we believed we would have an attribute as rich in detail as a fingerprint, as permanent as a fingerprint, but present on a larger scale. This latter point is a fundamental one for automatic recognition systems. It makes no matter how good an attribute is; the end result will depend just as strongly on how easily the attribute is transducible. The electrocardiogram (ECG) was selected because,

although not unique at the same level as a finger or palmprint, theoretical estimates indicated that ECG's could meet BISS specifications. It was further believed that the ECG could be used to produce a low cost system. This is in contrast to palm or fingerprints which require optical input devices with consequent greater cost.

Palmprints were collected from 72 people by placing their hands on a photocopying machine. The copies were marked at a number of fiducial points such as crease lines in the fingers and width of the fingers halfway between each crease line. Major crease lines of the palm were extended to their intersection with the silhouette of the hand to gain further fiducial points. These fiducial points were then digitized with a graphics tablet. Interpoint distances were computed to form thirty-four measurements on each palmprint. These measurements formed a 34-dimensional "feature vector" in the jargon of pattern recognition.

The next step was to find those subjects whose hands looked most similar under this measurement. With one feature vector per subject, we had 72 points in a 34-dimensional space. The Euclidean distance between all pairs of prints was computed, and a set of 25 hands comprising "worst case" pairs and triplets was identified therefrom. For each person in the group of 25, a set of 10 handprints was collected, the subject replacing his hand on the machine for each copy. Additionally, two more prints were collected for all 72 subjects.

This data was placed into the On-Line Pattern Analysis and Recognition System developed by PAR and RADC [1]. Using the measurement reduction routines in OLPARS, the 34 original measurements were reduced to nine which seemed to carry most of the distinctiveness between individuals. At this point, we were prepared to evaluate the Type I and II errors.

Let us denote the subjects by the symbols A, B, C, ..., and let us suppose that A is on the list of "worst case" hands. Thus thirteen handprints are available for A. Using ten of the thirteen prints, we designed a weighted nearest-mean vector logic [1] with a reject boundary. All three sets of 72 hands are tested against this logic. The three prints of A are used to determine a Type I Error. They should be accepted by the logic. The 213 other palmprints representing intruders should be rejected by the logic and can be used to determine the Type II Error. This procedure is then repeated for the next subject on the "worst case" list until all 25 subjects have been completed. Then the Type I and II Errors are computed as an average over the errors for each individual. These results are presented in Table 1-3.

We now turn to a discussion of ECG data. It is envisioned that this access control device will consist of two electrodes to which the person desiring access will touch his hands. We therefore collected ECG's with electrodes attached to the two index fingers of the subjects. No ground electrode was used, nor was any electrode paste. The subjects were told to stand normally. Thus, the recorded waveform is a highly modified ECG and to avoid medical connotations we have called it a "C-trace." ECG's were collected on 72 subjects over three sessions. The waveforms were digitized and

then entered into the PAR Waveform Processing System [4] for smoothing and automatic segmentation into individual beats. A ten-dimensional feature vector was extracted from the waveforms. The data was again manipulated in OLPARS in a fashion very similar to that described for the palmprints. The results are shown in Table 1-3.

The results of Table 1-3 are encouraging. The demonstration of feasibility on the cardiogram data is quite interesting in that the signal processing and feature extraction was almost totally automatic. The handprint still requires defining an appropriate imaging device and feature extraction algorithms, but the wealth of stable features on the palm of the hand indicate that extremely small error rates are attainable. We recommend continued development of both attributes, the C-trace for use in low security areas, at low unit cost, and the handprint for higher security areas, at correspondingly higher cost.

1.2. REPORT ORGANIZATION

Section 2 of this report describes the first task of the effort, the selection of two physical attributes for in-depth study. The second task, data collection on the chosen attributes, is given in Section 3. The final task, the analysis of the data and estimation of Type I and II error rates, will be found in Section 4. Section 5 provides our conclusions and recommendations.

1.3. ACKNOWLEDGEMENTS

The title page is only able to list the principal authors: much of the text for this report was generated by the individual engineers who researched the topics covered in Appendices C, D, and H. The engineers contributing to this project were N. Andres, D. Bennett, R. D'Amore, Dr. R. Erianne, Dr. F. Feng, Dr. H. Hersh, D. Lucey, Dr. J. Morris, and J. Wilson. Additionally, special thanks are due to Dr. D. Stowens, chief pathologist at St. Luke's Hospital, Utica, NY, who provided data and advice on palmprints. Also, Mr. Walter Hoetzer, New Hartford, NY, Secretary-Treasurer of the International Association of Identification, was very helpful to this project through providing access to his private library of works on identification.

SECTION 2

ATTRIBUTE SELECTION

Task I of this research consisted of compiling an extensive list of physical attributes for identity purposes. The attributes on the list were then reviewed in order to select the best two for in-depth data collection and analysis. The selection would complete Task I. In this section of the report, we present our methodology and results of the selection task.

2.1. EVALUATION PROCEDURE

Even from the earliest PAR staff meetings it was readily apparent that a long list of attributes was being generated for evaluation. It was felt that the evaluation would require significant library research and contacting of medical experts. Consequently, a team of over ten engineers was formed to obtain the facts necessary to perform the evaluation, each engineer typically being assigned a few attributes for investigation. The project staff was briefed at several meetings and given written guidelines for evaluation. The guidelines are reproduced in Appendix A.

The guidelines requested that the evaluator score each of his attributes on the basis of 100 points (perfect) in each category. He was not necessarily apprised of the weighting of the categories that would be employed in obtaining a numerical score for each attribute. The principal reason for not divulging the evaluation formula was that it had not been finalized, but a

secondary motive was to reduce possible evaluation bias. Note from Appendix A that engineers were asked to assume an advocacy note for their assigned attributes. A "devil's advocate" or negative position would be assumed by the evaluation comittee. Nevertheless, frequently the same people were involved in both defining the evaluation formula and researching the attributes so complete independence was impossible.

2.2. EVALUATION CRITERIA

The criteria by which an attribute was to be evaluated are listed in Table 1-2. We now discuss each criterion.

2.2.1. Separability

The separability category rated an attribute in regard to its Type I and II error performance. A Type I error in identity verification occurs when a person A, claiming to be person A, is rejected by the identity system. A Type II error occurs when a person X, claiming to be A, is accepted by the system. The goal of the study was to obtain a Type I error better than .01 and a Type II error better than .02.

Our procedure for estimaing separability was to develop formulas for Type I and II error rates. The development of the equations is relegated to Appendix B; here we present only the results. Let E_I and E_{II} be the Type I and II error rates respectively. Λ is the number of measurements (the dimensionality) made on the personal attribute. For example, if the attribute is

size, we might imagine measuring height and weight, in which case $\Lambda = 2$. The half range of the ith measurement over the entire population is denoted R_i, while the standard deviation in measuring the ith feature is σ_i. Then E_I and E_{II} can both be expressed in terms of the above variables and a tolerance parameter k, which measures the tolerance on a measurement in units of the standard deviation.

$$E_I = 1 - \mathrm{erf}(k/\sqrt{2})^{\Lambda} \tag{1}$$

$$E_{II} = k^{\Lambda} \prod_{i=1} \frac{\sigma_i}{R_i} \tag{2}$$

Equations (1) and (2) clearly shown the trade-off which exists between E_I and E_{II}. If E_I is fixed at .01, for example, by suitable choice of k, then E_{II} is determined.

For many attributes, Λ, R_i, and σ_i could be estimated from physiological data. The engineers reviewing each attribute were requested to fix E_I at .01 and use the resulting E_{II} as the separability evaluation.

2.2.2. Acceptability

Another important point on which to judge an attribute is its acceptability to the user. Measurements which produce embarrasment, pain, or apprehension in the user should be eliminated. Our procedure for evaluating this important criterion was to employ a staff psychologist to design and

evaluate a survey to determine acceptability. The survey and results are contained in Appendix C.

2.2.3. Feasibility

The technological feasibility is an important criterion for two reasons. First, many of the attributes to be investigated had only been demonstrated in laboratory environments. To bring the technology to a point where it could be employed for access control might take many years of development. Second, feasibility can be strongly interlinked with separability in that an attribute which might exhibit high intrinsic separability might be less attractive if methods of transducing the attribute are found to degrade its uniqueness. Fingerprints are a good example of this problem. Fingerprints are believed to be unique to an individual. Unfortunately, the scale of the friction ridges and the minutiae which produce the uniqueness make fingerprints a very difficult attribute to utilize. Thus, the feasibility of obtaining a separability equal to the known uniqueness of fingerprints is essentially zero. One must use a lower estimate of separability to achieve a non-zero feasibility.

2.2.4. Cost

Three categories of cost were considered: development cost, purchase cost, and maintenance cost.

2.2.5. Speed

The time required for personnel to gain access was also evaluated. This proved to be a useful category for eliminating some of the more exotic attributes such as blood composition.

2.2.6. Penetrability

In the penetrability category, we estimated how easily a determined intruder might pass the system. This is to be distinguished from Type II error which refers to penetration by a casual intruder. The casual intruder is assumed to be drawn at random from the general population.

There are two aspects to penetrability. The determined intruder must first "steal" the attribute from a legitimate entrant candidate and then duplicate that attribute in such a manner as to defeat the system. External attributes such as fingerprints are generally easier to steal than internal attributes like electrocardiograms. Electrocardiograms might be simply duplicated, however, with an FM tape recorder. Fingerprints might prove more difficult, depending upon the method used for transducing the print.

2.3. ATTRIBUTE EVALUATION

The thirty-three attributes were investigated and reports on most are collected in Appendix D. From these reports, and from the survey on acceptability described in Section 2.2.2., Table 2-1 was produced. Table 2-1 lists

CRITERIA / ATTRIBUTES	SEPARABILITY	ACCEPTABILITY	FEASIBILITY	COST	SPEED	PENETRABILITY	CONFIDENCE
1. Palm print		85	70		80	60	60
2. Finger folds		85	70		90	60	60
3. Finger lengths		85	100		90	80	100
4. Skin/hair color	40	92	90	—	100	40	—
5. Vein pattern		85	60		80	80	60
6. PPG time delays		85	80		95	80	60
7. Skin resistance	0	75	90	—	100	60	40
8. Body resistance	—	—	40	—	100	40	40
9. Tremours	40	85	90	90	75	80	40
10. Bone pattern		47	70	30		100	60
11. IR radiation	—	—	—	—	—	60	40
12. Eye scan/dilation	—	—	60	—	—	80	40
13. Sonic...skull	—	47	—	—	—	—	60
14. Bite pattern	—	—	—	—	—	—	40
15. Ear structure		68	70		80	40	80
16. EEG	—	—	—	—	—		80
17. VEP		55	40[A]		95	100	60
18. VEM	—	68	—	30	—	—	40
19. Saliva	—	—	—	—	—	—	60
20. Blood comp.	—	10	0	—	—	—	100
21. Odor	—	—	30	—	—	—	40
22. Height/weight		84	100	100	100	20	100
23. Gait	—	—	30	—	—	100	60
24. ECG		75	90	90	90	80	80
25. BCG		80	70	70	90	100	40
26. Verbal Response	—	—	—	—	—	80	80
27. Personal Hist.		47			75	80	80
28. Typing Style		83	100	100	100	80	80
29. Lip Grooves	—	47	60	—	75	40	40
30. Polygraph	—	—	—	—	40	—	—
31. Implanted tags		0	—	—	—	—	—
32. Body vibrations		80			90	100	60
33. Nail grooves		70	60		100	40	60
WEIGHTS	4	3	2	2	2	1	

A. No way to attach electrodes

Table 2-1 Personal Attributes Verification Attribute Evaluation

the thirty-three attributes in the left-hand column. Along the top of Table 2-1 are the criteria on which the attribute was evaluated. The row of numbers following each attribute indicates its score on the basis of 100 in each category. Frequently, the evaluation committee used its judgement to temper some of the ratings given by the researchers. Some entries of Table 2-1 are left blank where it was obviously impossible to arrive at a numerical value. The final column of Table 2-1, is a number assigned by the evaluation committee, again from a minimum of 0 to a maximum of 100, to indicate a subjective evaluation of confidence in the six numbers assigned in the other categories.

2.4. CHOICE OF TWO BEST ATTRIBUTES

The evaluation committee began its work with the numerical scores recorded in Table 2-1. Because many scores were either unavailable or not needed, many gaps occur in the table.

The formula for evaluation of the attributes was basically a weighted sum of all the categories. The exception to this rule was that we required a minimum score of 50% in all categories. The weights assigned to each category are shown at the bottom of Table 2-1. Separability and acceptability were favored by the weighting formula. Cost and feasibility were de-emphasized since it was felt that technological advances might alter these categories.

In discarding attributes which failed to achieve the minimum score of 50% in all categories, the confidence assignment was considered to be a separate category. This was felt to be a mechanism for eliminating attributes which

might superficially appear worthy of study, but for which detailed or reliable information was lacking.

Applying the above strategy, we were able to eliminate from further consideration skin/hair color, skin resistivity, body resistivity, finger tremour pattern, bone pattern of the hand, IR radiation pattern of the hand, eye scan paths, sonic characteristics of the skull, bite pattern, ear structure, electroencephalograph, visually evoked potential, visually evoked magnetic field, saliva, blood composition, odor, height/weight, gait, ballistocardiogram, verbal response, personal history, lip grooves, polygraph, implanted tags, and nail grooves. The detailed discussions will be found in Appendix D. However, we briefly summarize here the reasons for eliminating these attributes. Skin and hair color were felt to be too variable to achieve a satisfactory rating. Skin resistivity was a physiological attribute which is simple to measure, but apparently quite useless for identification due to its variability. Body resistivity, as measured by an oscillating magnetic field, was an interesting attribute because it was non-invasive (assuming low power dissipated in the body). However, the problems associated with metallic objects on the subject seemed difficult to handle. The suggestion that the metallic objects would exhibit a different phase in the complex conductivity was made, but the technological risk was high as this method has not been tested. Bone patterns of the hand were to be measured with ultra-sound. Since there appeared no way to avoid immersing the hand in water, this attribute was rejected as being unacceptable to the user. IR radiation pattern of the body or hand was never investigated sufficiently to make an evaluation. This attribute was consequently eliminated on low confidence

rating. Similar remarks apply to eye scan paths. Sonic characteristics of the skull was eliminated due to a low acceptability score since it was felt that adequate signals could only be obtained at the expense of some user discomfort. Bite patterns and teeth were also eliminated on the basis of low acceptability, however, in this case, the reasons were more psychological. Our survey on user acceptability indicated that any measuring device attached to the head was perceived as a higher threat than similar attachments to the extremities. In particular, the hand is a convenient and acceptable place to perform a measurement. Ear structure was eliminated due to low penetrability score. The evaluation committee felt it would be a simple matter to observe someone's ear structure and duplicate it, perhaps with a false ear, with very low probability of detection, even by a human observer. Many of the lineal features which would be measured on the ear are morphologically similar to lineal features on the hands. Since the hand will probably be brought into contact with the measuring device, tests could be performed to determine whether a false hand or glove was being used. (One might test for the presence of a PPG signal, for example. See Section D.4.) Conversely, since the imaging of the ear would be done remotely, no such test could be performed. Also, the hand is much more easily brought to the sensing device than the ear. In short, the hand has the advantages of the ear, richness of detail and uniqueness, but lacks many of the disadvantages. Electroencephalography was eliminated in favor of the closely related, active technique of visually evoked potentials (VEP). VEP was itself eliminated due to low feasibility score. No method of easily attaching electrodes was discovered. Although, in light of the excellent results we eventually obtained on electrocardiograms with dry electrodes, VEP is perhaps worth new consideration. Visually evoked

magnetic fields would be too costly to pursue. A good deal of low temperature equipment would need to be assembled. Saliva was ruled out for low technological feasibility and low confidence. Its uniqueness and the capability to analyze saliva in an entry access environment was not convincingly demonstrated by the research. Blood composition tests were not acceptable to the users, in fact scoring lowest. Odor detection at the required concentrations appears to yet be beyond present technology. Height/weight measurements were eliminated due to low penetrability score. However, a combination of these measurements with other simple physical attributes still appears a viable technique, although outside the scope of the present investigation. Gait was eliminated when no automatic measurement technique was apparent. The ballistocardiogram was eliminated in preference to the more easily investigated electrocardiogram. Verbal response and personal history were rejected as being outside the scope of the investigation. They further demand certain basic literacy levels which make them not ideally suited for all applications. Lip grooves were eliminated for low acceptability. The polygraph would take too much time and was therefore rejected. Implanted tags were judged unacceptable. Body vibrations are being pursued by others and results are not yet available. Finally, nail grooves scored poorly in the penetrability category. As in the case of ear structure, the evaluation committee felt that the system could be easily defeated with a false nail overlay and that no simple tests to detect the fake nail were available. Thus, most attributes were eliminated through this preliminary screening.

The remaining attributes are collected in Table 2-2. The evaluation committee also listed a group of attributes of secondary rank. We cannot

Table 2-2 Personal Attributes Remaining in Survey after Preliminary Screening

Palm prints	
Finger folds	Can study as one attribute
Finger geometry	
Vein patterns on back of hand	
Electrocardiograph	

Table 2-3 Personal Attributes Eliminated from Study But of High Rank

Visually Evoked Potential
Personal History (Question/Answer)
Ballistocardiogram

Table 2-4 Personal Attributes Eliminated from Study But of Potential Use in Combination

Finger lengths (Identimat Corp.)
Typing style
Height/weight
PPG Time Delays

overemphasize that opinions came strongly into play in the final attribute screening. Those attributes eliminated are not being rejected as unusable in the future. Indeed, technological breakthroughs are apt to make almost any one of the physical attributes studied a viable technique for automatic identification. Table 2-3 lists those attributes which came closest to meeting the criteria and will perhaps be useful in the future. Table 2-4 summarizes attributes which were eliminated on the basis of low separability scores, but which appear to have the advantage of being measurable at low cost. They would thus be useful in combination with themselves and other simple attributes.

It was felt by the evaluation committee that the first three attributes of Table 2-2 could be combined in one pilot study. How this was accomplished is discussed in the following section. Vein patterns on the back of the hand were felt to be of high interest, but in regard to feature extraction, very similar to palm lines. Electrocardiographs had the nice property of employing a transducer technology distinctly different from that of the palm prints and vein patterns. This was felt to be valuable for lowering the technological risk of Phases II and III of this investigation. Consequently, the two attributes selected were handprints (actually, a combination of palm prints, finger folds, and finger geometry) and electrocardiograms (actually, a highly modified lead system). With these choices, Phase I was complete. Data collection and analysis on the two chosen attributes remained.

2.5. DISCUSSION OF TWO SELECTED ATTRIBUTES

The major reason for selecting the handprint as an attribute to be studied further was our judgement that it is sufficiently rich in detail to meet even the most stringent error specifications. This richness is illustrated by the fact that all three attributes of Table 2-2 can be measured at the same time, yet they are all independent and can contribute therefore to an excellent separability. The three attributes of palm prints, finger folds, and finger geometry can be measured simultaneously from a single image. If the hand is illuminated obliquely from the front (palm) side against a dark background, then the silhouette will permit extensive measurements of finger geometries. The silhouette of the hand produces crisp outlines from which the endlessly variable shapes of the finger, blunt, conical, tapering, crooked, may be extracted. The creases of the finger folds and palm fold lines will be enhanced by the oblique illumination. We believe that the friction ridges of the palm, although as unique as those of the finger tips, are too small to permit good measurements.* The flex lines of the fingers will permit measurement of finger segment lengths and provide fiducial points at which to measure finger widths. The flex lines of the palm are not only of a size to permit resolution by straightforward devices, but are rich in detail. In the subsequent sections we shall refer to the attribute as "handprint," and this term will mean (1) finger and hand geometry measurable from the silhouette plus (2) finger flex lines plus (3) palm flex and crease lines.

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* The same objection applies to fingerprints, although Calspan Corp. is pursuing an identification system based on the fingerprint. Any results of their investigation will be more useful for assessing the performance of the technique than hypothetical speculation.

The major reason for selecting the ECG as a physical attribute is that it appears to have adequate separability and also appears to be capable of rapid technological development. This latter point follows from the fact that electrocardiography is an ancient medical technique when measured on a time scale consistent with the rapid advances in medical science the last two decades have produced. Furthermore, extensive work has already been done on automatic processing of ECG's for computer diagnosis and storage. We will thus be building on established fact. Finally, there appears to be no technology gap in any area of ECG's for access control, no new amplifiers, scanners, jigs, rigs, or high speed processors. If the ECG can be shown to work satisfactorily, then all of the above argue that development, installation, and maintenance costs can be agreeably low compared to other access control devices.

As we have already mentioned in Section 1.1. and will describe in more detail later, the method of ECG measurement we shall employ consists of two dry electrodes attached to the index fingers. This is not a medical lead system and to avoid any medical connotation to the measurement we have named it C-trace ('C' for "cardiogram").

An interesting aspect of the C-trace is that it is a much more private attribute than voice, fingerprints, finger lengths, or handprints, which are all externally visible. The C-trace is similar to signature verification (which actually measures pressure history of the signature) and body vibration transfer function which are internal and remain hidden. These latter attributes would appear much less susceptible to hostile penetration due to their covertness.

A disadvantage of the C-trace is that the time to record the necessary heartbeats, perhaps eight, will always be five seconds or so, placing an upper limit on throughput. Additionally, although our survey determined the C-trace to be acceptable to users, it did not score as highly in this category as handprints.

In the next two sections we describe in detail the data collection and processing which produced the error results quoted in Table 1-3.

SECTION 3

DATA COLLECTION (PHASE II)

This section sets forth the methods by which the handprint and cardiogram data were collected. The hardware configurations are described and samples of the data are presented. The amount and structure of the data obtained for further processing is also given.

3.1. HANDPRINTS

To demonstrate the feasibility of using handprints for verification purposes, a large amount of data is required. Thus, any means of handprint collection must be convenient as well as accurate. Not only does a large photocopying machine meet these specifications, but it also provides a permanent record of all data.

Distortion introduced by the copier was of some interest. To determine the distortion errors produced by a copier, the following simple experiment was conducted.

Step 1: Draw straight lines at various locations on white paper.

Step 2: Measure the lengths of these lines with a magnification comparator.

Step 3: Make a copy of the paper. The location of the original was carefully settled.

Step 4: Measure the lengths of the lines on the copy with the comparator.

Step 5: Calculate for each line the ratio of the original length to that of the copied one.

Figure 3-1 shows the original seven groups of lines. Each group consists of three vertical and three horizontal lines marked as shown. The lengths of these lines and the copies were measured with a Gurley Rapid Comparator Model 7055, and copies on two machines were generated: an IBM Copier II and a Xerox 4500. A summary of results is given in Table 3-1: full results for each line appear in Tables 3-2 and 3-3. From this experiment it was concluded that the IBM Copier II is superior to the Xerox 4500 in both magnitude and uniformity of the magnification factor. Further experiments were performed with the results that the magnification is location dependent but time invariant.

In order to obtain the best possible hand image from the copier, images from a variety of hand orientations and several degrees of applied pressure by the hand on the copy surface were examined. As a result, all applicants were instructed in the same way: place the right hand comfortably but firmly on the copy surface, fingers spread. Cover it with a cloth, then position the left hand on the cloth over the right hand. The resulting image has sufficient detail to define and mark the features. A typical copy is shown in

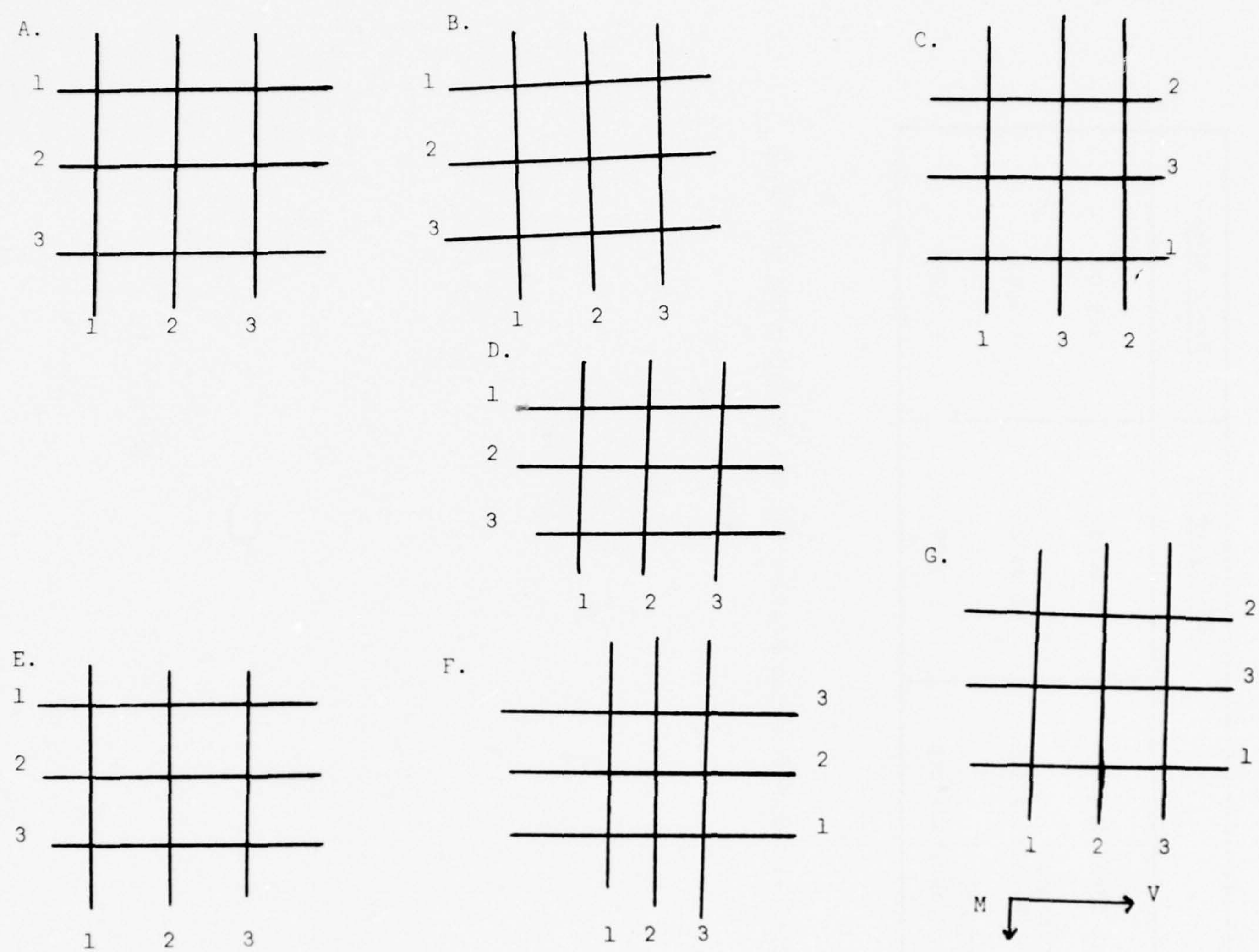

Figure 3-1 Test Grid for measuring photocopier distortion.

	IBM Copier II	Xerox 4500
Mean Magnification	1.0016	1.0104
Horizontal Magnification	1.0023	1.0085
Vertical Magnification	1.0009	1.0123

Table 3-1 Magnification Factors for Two Photocopying Machines.

Line ld	Original	IBM Copier II	Xerox 4500
AV 1	44.9	44.8	45.4
2	44.1	44.2	44.9
3	42.9	42.9	43.3
AH 1	44.2	44.3	44.6
2	43.4	43.4	43.5
3	43.0	42.9	43.5
BV 1	44.0	44.1	44.5
2	42.2	42.3	42.7
3	42.2	42.4	42.7
BH 1	42.4	42.6	42.8
2	43.2	43.4	43.5
3	42.8	42.9	43.0
CV 1	46.4	46.4	46.9
2	47.1	47.3	47.8
3	47.9	48.1	48.6
CH 1	39.3	39.1	39.4
2	37.4	37.0	37.7
3	37.6	37.3	38.1
DV 1	34.9	35.1	35.3
2	35.1	35.3	35.5
3	36.6	36.8	37.1
DH 1	42.2	42.4	42.6
2	42.5	42.6	42.8
3	38.0	38.3	38.4
EV 1	39.7	39.7	40.2
2	38.5	38.4	39.1
3	38.5	38.5	39.0
EH 1	45.5	45.8	46.0
2	44.7	45.0	45.3
3	43.4	43.6	43.8
FV 1	40.0	40.1	40.4
2	40.2	40.4	40.6
3	39.8	40.0	40.4
FH 1	46.2	46.5	46.6
2	46.9	47.2	47.4
3	47.5	47.8	47.9
GV 1	43.7	43.8	44.2
2	44.7	44.9	45.2
3	44.7	44.7	45.1
GH 1	42.4	42.1	42.8
2	42.8	42.4	43.0
3	43.4	43.1	43.8

Table 3-2 Line Lengths in Machine Distortion Study (mm)

Machine	Orientation	Line Id	A	B	C	D	E	F	G
IBM Copier II	Horizontal	1	1.0023	1.0047	1.0000	1.0047	1.0066	1.0065	0.9929
		2	1.0000	1.0046	1.0042	1.0023	1.0067	1.0064	0.9907
		3	0.9977	1.0023	1.0042	1.0079	1.0046	1.0063	0.9931
	Vertical	1	0.9978	1.0023	0.9947	1.0057	1.0000	1.0025	1.0023
		2	1.0023	1.0074	0.9893	1.0057	0.9974	1.0050	1.0045
		3	1.0000	1.0047	0.9920	1.0055	1.0000	1.0050	1.0000
Xerox 4500	Horizontal	1	1.0090	1.0094	1.0025	1.0095	1.0110	1.0087	1.0094
		2	1.0023	1.0068	1.0080	1.0071	1.0134	1.0107	1.0047
		3	1.0116	1.0047	1.0113	1.0105	1.0092	1.0084	1.0092
	Vertical	1	1.0111	1.0114	1.0108	1.0115	1.0126	1.0100	1.0114
		2	1.0181	1.0118	1.0149	1.0114	1.0156	1.0100	1.0112
		3	1.0093	1.0118	1.0146	1.0137	1.0130	1.0151	1.0089

Table 3-3 Magnification Factors of Copy Machines

Figure 3-2. Unfortunately, the quality of reproduction in technical reports degrades the quality of the original photocopy image considerably.

Handprints by their nature are quite stable in time (see Section D.1). Thus, no individual variation was expected during the time frames involved in the handprint data collection. The handprint images were obtained at any time convenient to both the researcher and the subject.

The handprint data is arranged in two formats. All 72 subjects had handprints collected on three days. Then 25 were chosen for detailed study. For these 25 people, 10 additional handprints were collected. The 25 people were selected as follows:

First, one handprint from each of 72 people forms a reference set. There are three such sets, each collected on a different day. Measurements were extracted from the first reference set, a process described in detail below. Additional processing was used to measure the similarity (Euclidean distance [2]) between each pair of hands (individuals). The sets of vectors that were closest together thus corresponded to those hands that were most similar. The 25 worst cases, the hands most likely confused, form the second data file.

An additional ten different images of each of these hands were collected at one time. By choosing the worst cases, those hands most similar, the error estimates obtained from the classification logic could be considered to be the worst possible performance of the logic. Choosing hands less similar should decrease the error rates.

Figure 3-2 Typical Handprint collected by photocopier.

In any dedicated system, the handprint collection and feature extraction must be accomplished automatically. To date we have investigated the achievable resolution of the parts of the hand by using a television camera and have concluded that a satisfactory image can be obtained (Appendix H). The algorithms by which the features are found and measured from the image have not been developed.

3.2. CARDIOGRAMS

Because any dedicated verification system must be acceptable to its users, all cardiogram data was collected in a simple manner. Two electrodes were attached to the index fingers without a ground lead or electrode paste. Figure 3-3 depicts a data collection session. A stripchart recording of typical signals measured by a Hewlett-Packard 1500B Electrocardiograph is shown in Figure 3-4. The horizontal scale is .4 sec/cm; the vertical scale, 1 mV/cm.

During the data collection phase, each person at each of three sessions had recorded a 30-40 second tracing. To manage such a large amount of data, all tracings were recorded on an FM analog tape recorder and later digitized at a convenient time. Each person was told to stand erect but comfortably and was requested not to move or speak since the technique is sensitive to any other muscular activity.

The configuration in Figure 3-5 was used to record the data. The recorder electronics were calibrated to a 100 Hz 20V p-p sine wave before each

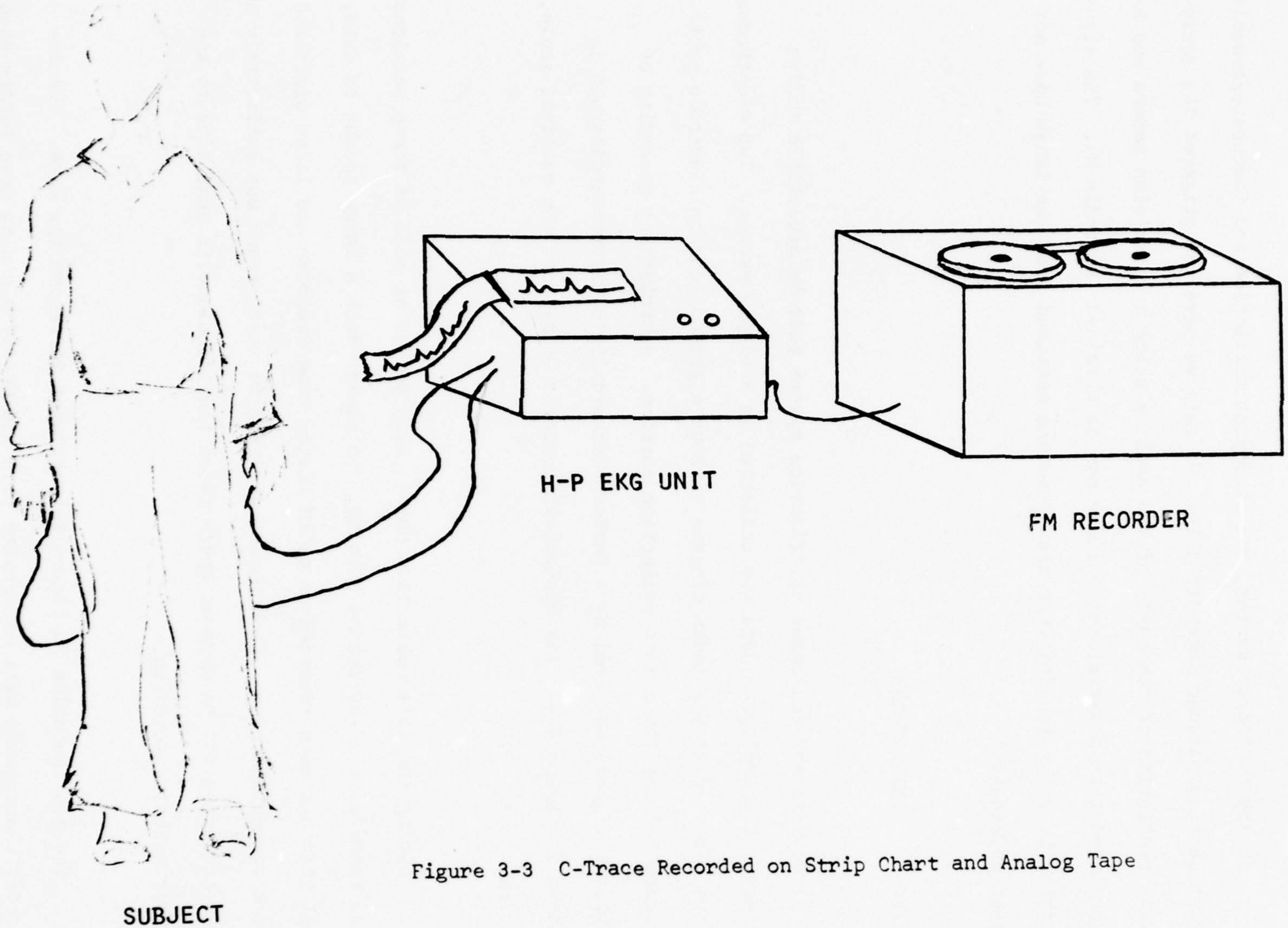

Figure 3-3 C-Trace Recorded on Strip Chart and Analog Tape

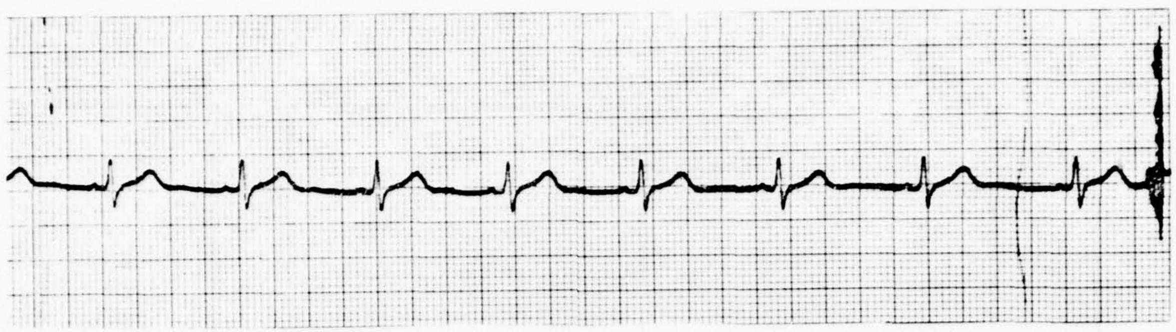

Figure 3-4 Stripchart Cardiogram Recording

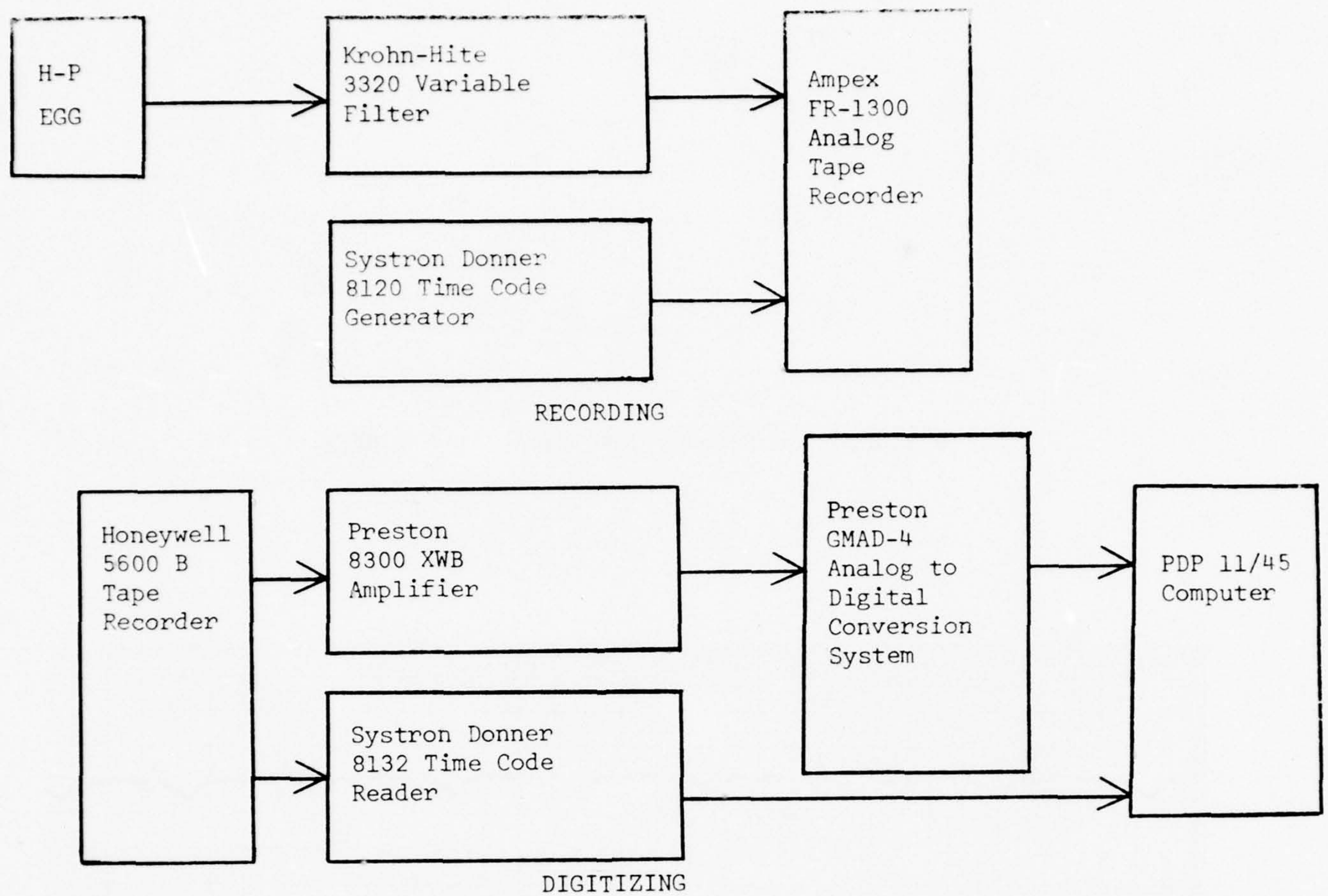

Figure 3-5 Electronic block diagram for recording and digitizing ECG data.

recording session. The filter was low pass with a 3 kHz cutoff frequency and had a gain of 20 dB. The data and the time code were recorded simultaneously on non-adjacent channels of the recorder.

The Hewlett-Packard 1500B has a high-gain differential input. The cardiogram signal rides on a large and time-varying DC offset which must be balanced out manually to bring the output voltage of the 1500B differential amplifier into a range where it can be recorded on analog tape. This balancing was accomplished manually at the time of data collection by visually monitoring the stripchart needle on the 1500B and adjusting the DC bias control on the unit.

Playback of the data was accomplished with the configuration depicted in Figure 3-5. The amplifier was used in the variable gain mode, and was set at the beginning of each digitizing session so that a calibration signal out of the electrocardiograph resulted in a digital signal of the same amplitude. The A/D converter has 15 bit capacity, and we used this full range to accommodate the full input signal of 2 mv peak-to-peak. The power signal-to-noise ratio due to the sampling procedure is

$$SNR = 3.2 \times 10^9 \, P$$

where P is the mean square value of the input cardiogram signal expressed in (millivolts)^2 [3]. For a typical value of $P = (.1 \text{ mv})^2$,

$$SNR = 75 \text{ dB}.$$

This SNR is greater than the signal quality, so no appreciable noise is added by the digitization process. In addition, the medical literature suggests that the bandwidth of ECG's is fairly low, less than 100 Hz. (Appendix B). The sampling rate used was 1 kHz, quite sufficient to obtain all relevant frequency information. Figure 3-6 shows a typical data sample immediately after digitization, and Figure 3-7 shows the power spectrum of this data. The SNR is approximately 45 dB, and the signal energy appears at below 200 Hz. Noise at the line frequency and its two harmonics are prominent. The 1 kHz sampling rate thus represents an oversampling by more than a factor of two over the Nyquist [3] rate.

Table 3-4 summarizes the cardiogram data obtained at the three sessions. It should be noted that tracings from some people were recorded at different gain settings on the electrocardiograph itself to provide for full use of the allowable signal range. In addition, the totals given represent the number of people from which the indicated number of tracings were received, regardless of when those tracings were recorded. Time constraints did not permit all subjects to participate in the collection at all three sessions. Thirty of the forty-seven people for which there are three tracings account for the data subsequently used for the logic evaluation.

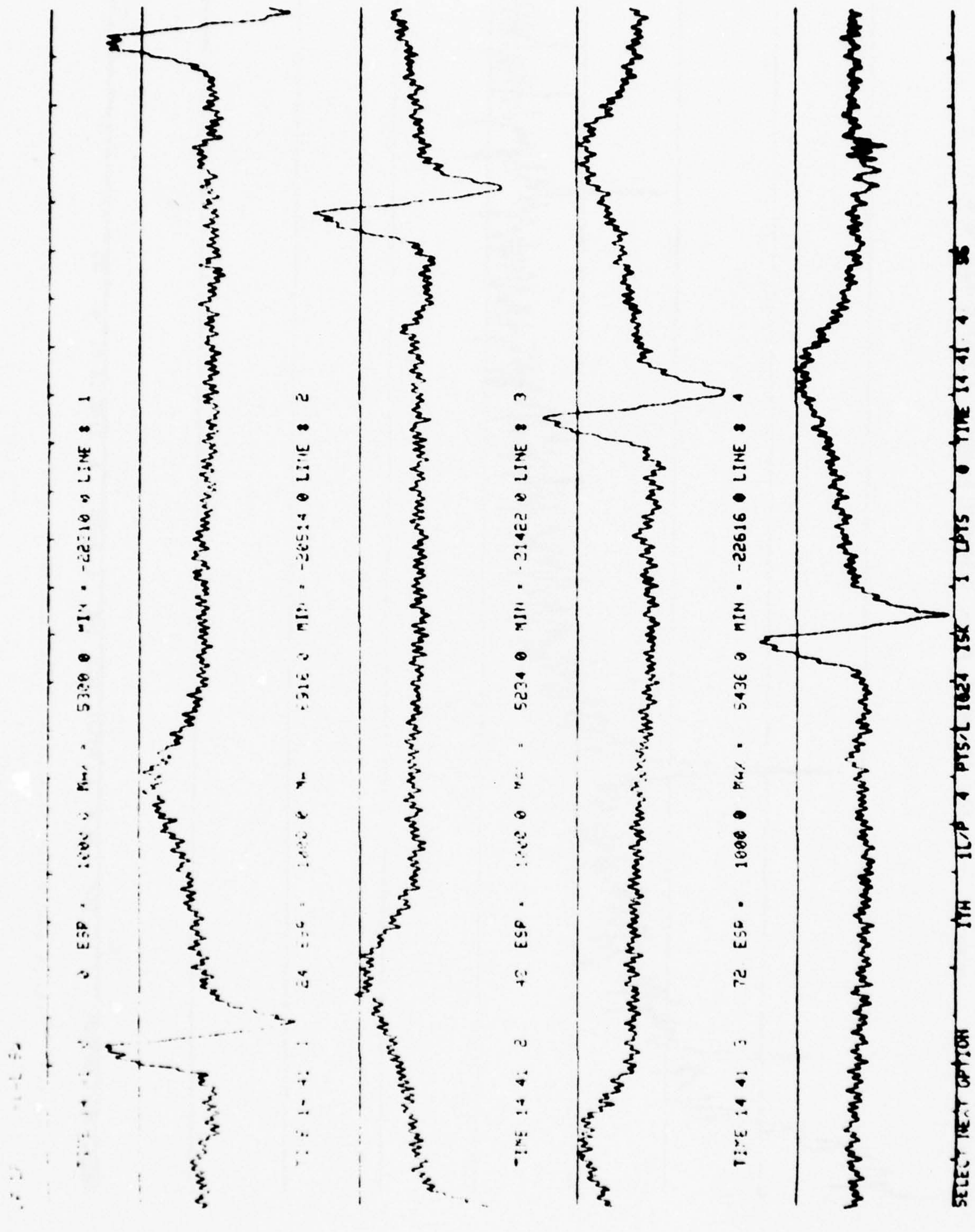

Figure 3-6 Typical Cardiogram Trace.

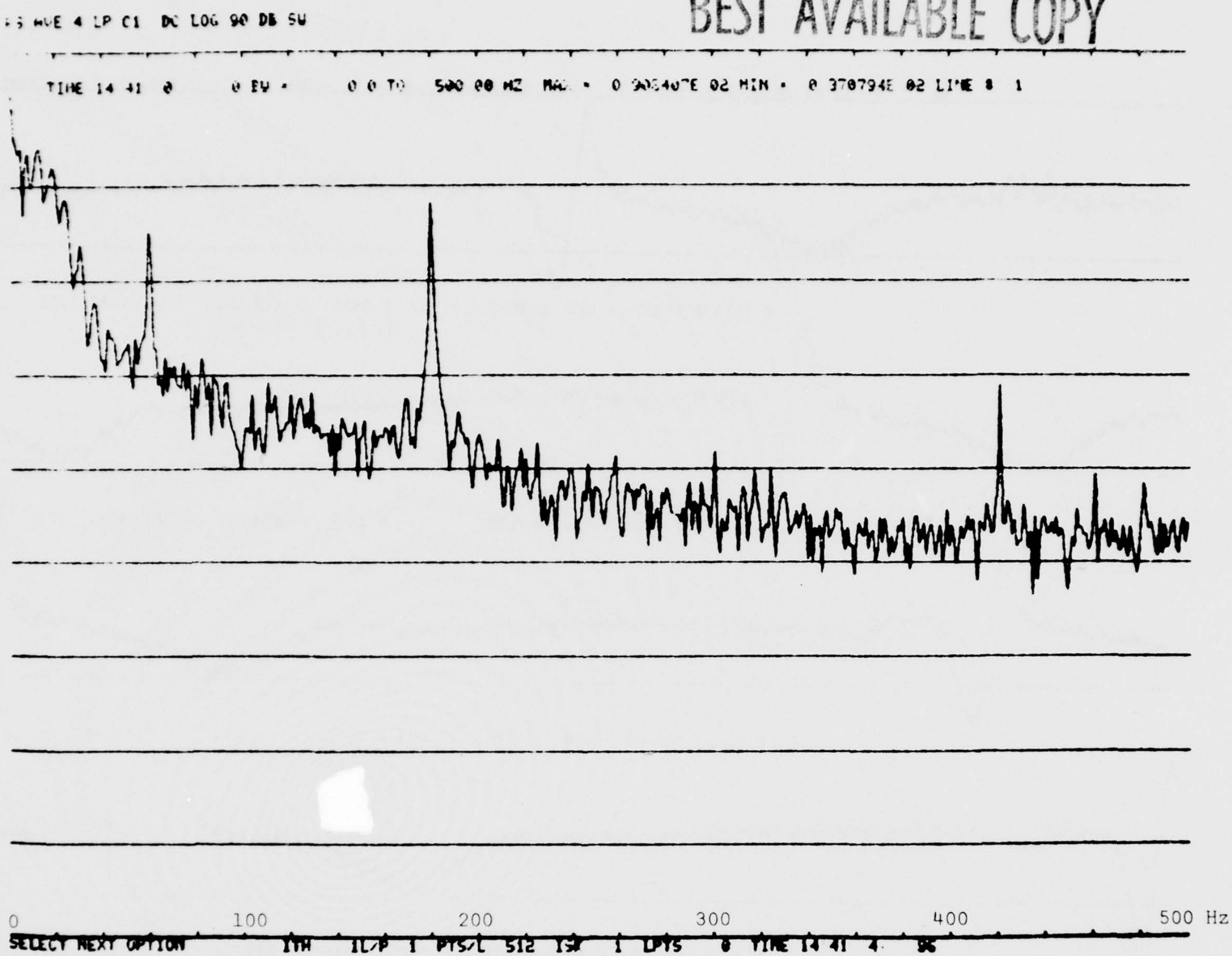

Figure 3-7 Logarithmic Power Spectrum of Cardiogram.

Session	Date	Number of Different People	Number of Tracings
1	13 Jan 77	57	65
2	19 Jan 77	44	49
3	8 Feb 77	49	85

Totals

Number of Tracings	Number of People
3	47
2	10
1	10

Table 3-4 Cardiogram Data Collection.

SECTION 4

DATA ANALYSIS (PHASE III)

This section describes how the data collected during Phase II, both handprints and ECG's, was analyzed. Results in Type I and Type II errors are given.

4.1. HANDPRINTS

In this section, we present the error estimates obtained for the handprints and the processing used to obtain them. The error estimates are encouraging and confirm that enough information does exist in a handprint to perform verification in a dedicated system. Since the handprint features were extracted manually, very little processing of the features was necessary. Before the error results are presented and explained, the features themselves are discussed.

4.1.1. Feature Definition and Extraction

The most striking characteristics of a hand are the sizes of its various parts. Figure D-1 shows the major bones of the hand. Though we cannot easily measure their dimensions, they do suggest their sizes by the position of the creases on the hand itself. The creases appear where the bones allow the fingers and hand to bend, and should therefore provide ample information about the sizes of the parts of a hand to distinguish one hand from another.

Figure D-2 shows the main creases in the hand. From Figures 3-2 we observe that one of the most outstanding features on the hand image is the creases.

One strategy for defining a first set of features is to use as many of them as are thought to contain information relevant for verification. Afterwards, those features not contributing much information can be discarded, and a more manageable feature set can be determined. This is indeed the strategy chosen for the handprints, since the cost in time and complexity for extracting additional features is diminishingly small. Consequently thirty-four features were defined as shown in Figure 4-1. Subsequent feature analysis in OLPARS [1] resulted in the choice of nine features for the reduced feature set. These nine were deemed the most distinguishing measurements of the original 34 relative to our 72 person data base and are shown in Figure 4-2.

After a hand is copied, the eighteen endpoints defining this reduced feature set are manually marked on the copy, then entered into the computer with a Tektronix 4953 Data Tablet. This digitization results in the features shown graphically on the computer display as in Figure 4-3. Once these points are entered into the computer, the features are computed and submitted to logic design and evaluation.

4.1.2. Logic Design and Evaluation

The method used to analyze the feature vectors develops from the typical scenario describing the use of this data in a dedicated system. An applicant requesting access to a classified area inputs a password to the system. This

PHALANX WIDTHS: 1, 2, 3, 4, 5, 7, 8, 9, 11, 12, 13, 15, 16, 17

MPC LENGTHS: 6, 10, 14, 18

PHALANX LENGTHS: 19 - 32

PALM WIDTH: 33, 34

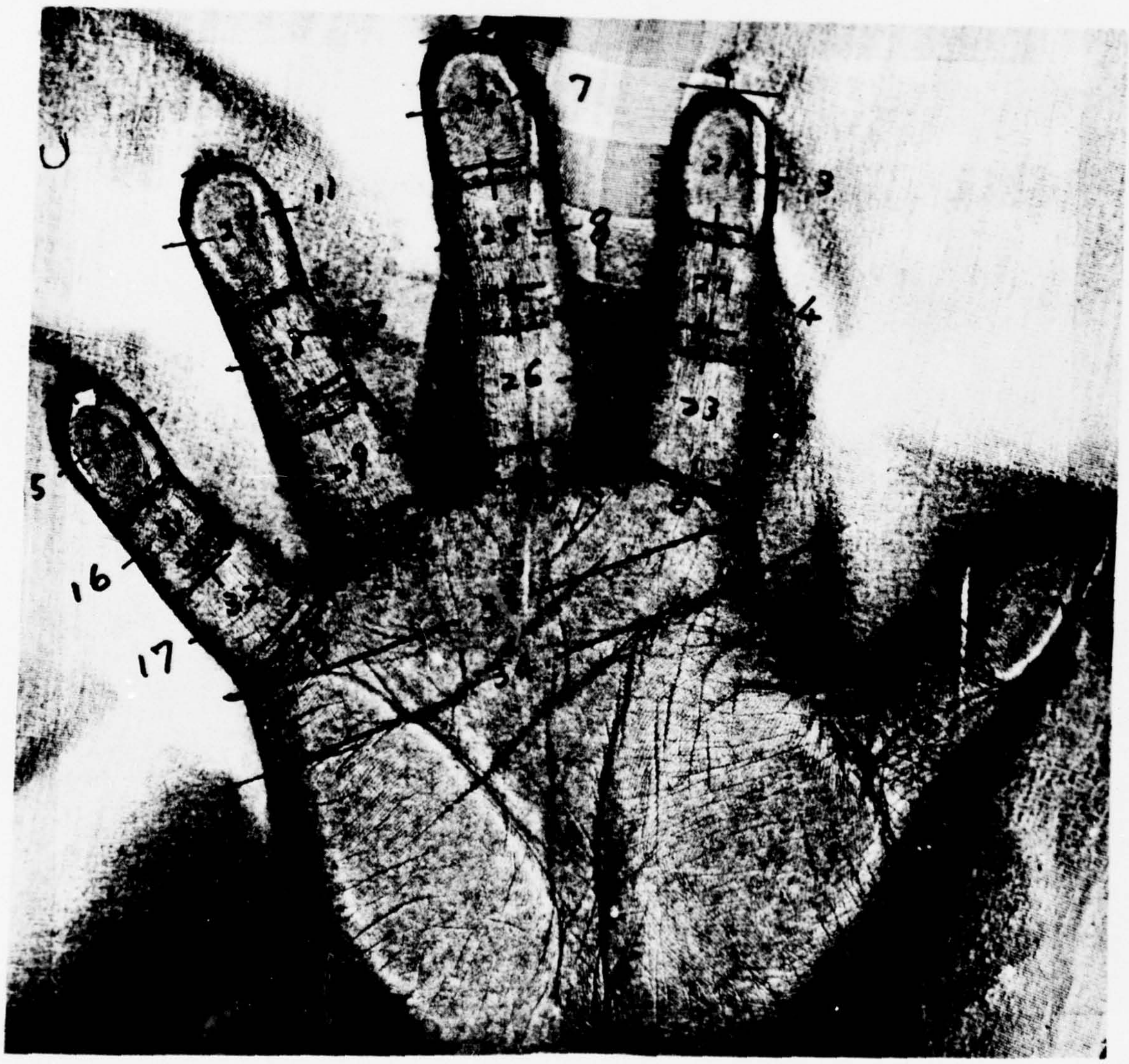

Figure 4-1 Thirty-Four Handprint Features

Figure 4-2 Nine Handprint Features

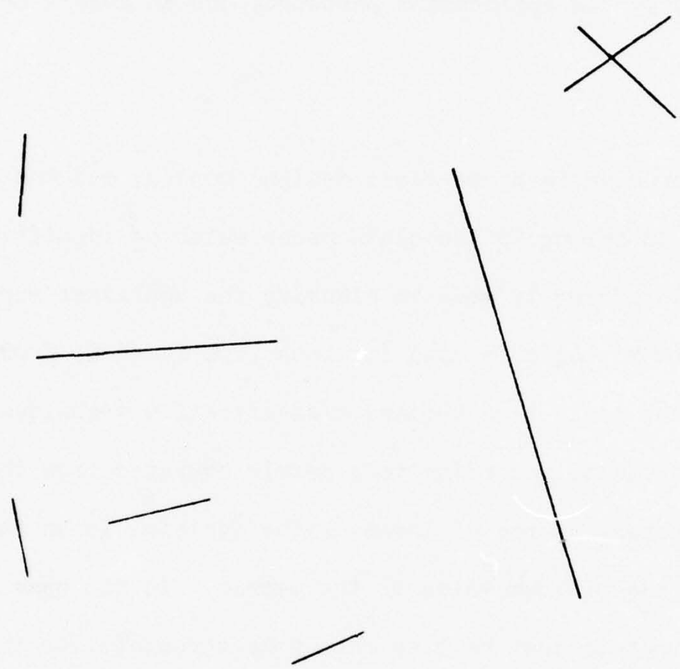

Figure 4-3 Computer Display of Nine Handprint Features

password indicates to the system under which identity he is attempting to gain access. The system now digitizes an image of the applicant's hand, by a television camera, for example, and automatically extracts the features. This feature vector is then compared to the mean vector of the identity class previously determined by the applicant's password, and an accept or reject decision is made.

Note that this problem is a one-class design problem, and the applicant either is determined to belong to the class under which he identified himself or he is rejected. No effort is made to classify the applicant further. Nearest Mean Vector (NMV) logic is used for both Type I and II Error evaluations. Generalized NMV logic is a k-class classification technique; it classifies an unknown vector according to a metric computed from the unknown vector to the mean vectors of the k classes. The decision is in favor of the class which produces the minimum value of the metric. In the case here, k=1 and the value of the metric must be less than some threshold for the unknown vector to belong to the class; otherwise, the vector is rejected. The metric chosen is the weighted Euclidean distance; hence we require the variances of the design vectors along each coordinate.

The handprint data is arranged in two files, is shown schematically in Figure 4-4. First, one handprint from each of 72 people forms a reference set. There are three such sets, each set having been collected on a different day. After processing the first reference set to obtain the feature vectors, an additional processing step is used to determine those feature vectors, and

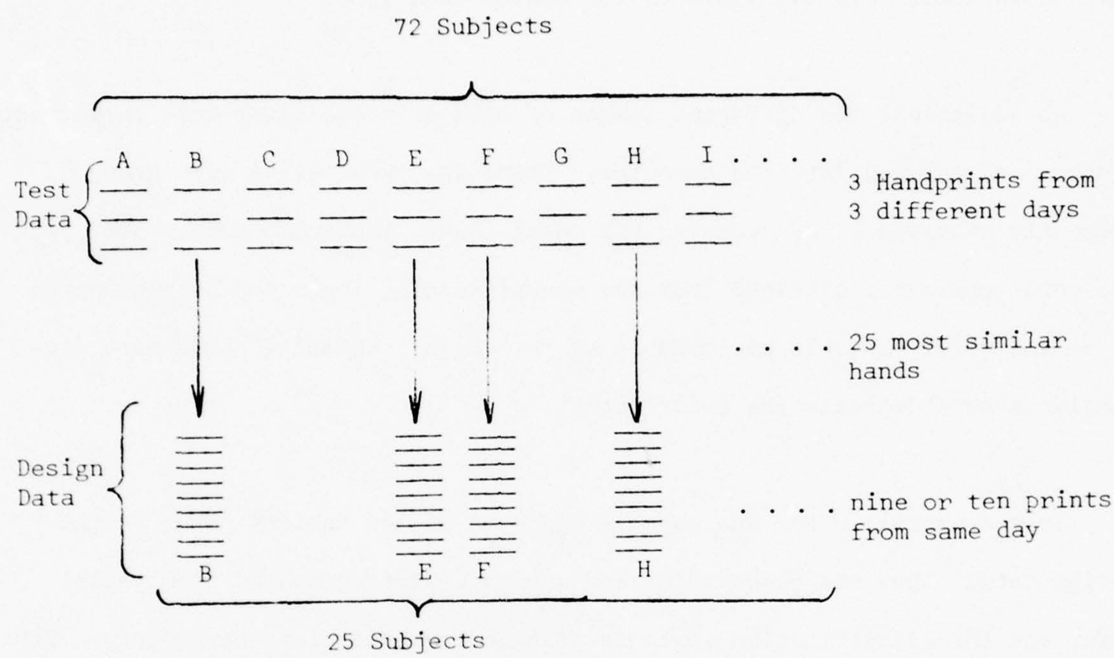

Figure 4-4 Pictorial representation of the two types of data collected, design data and test data. Each line indicates a handprint.

hence those hands, that are most similar. These worst cases, the hands most likely confused, form the basis of the second data file.

An additional ten different images of each of these hands were collected, marked, and entered into the computer. There are twenty-five such groups presently available. By choosing the worst cases, those hands most similar, the error estimates obtained from the classification logic can be considered to be the worst possible performance of the logic. Choosing hands more dissimilar should decrease the error rates.

In the overall error analysis, the groups of ten vectors serve as the design sets. Thus the class means and variances are estimated from these sets, and the classification logic is designed on each class separately. For the error estimates presented in Figure 4-4, each design logic was evaluated using all other design sets and the three reference sets, with the results for each class averaged together. For example, using the notation of Figure 4-4, weighted NMV logic is designed on the ten design vectors of subject B. A reject boundary is employed. The three test data vectors of B are then submitted to the logic. Any rejection is, of course, a Type I Error. Similarily for E, F, H, etc. The Type I Errors for all 25 of these design hands are averaged to obtain an overall Type I Error estimate. Thus, if B and F each have one of their respective three test handprints rejected by the logic, the average Type I error would be 2 errors out of 75 attempts (3 test hands x 25 subjects = 75 attempts). To arrive at a Type II Error estimate for subject B's entry code, subject A, C, D, E, F, ... test data and subjects E, F, H, ... design data are submitted to the logic. The number of vectors accepted

divided by the number of attempts (24 x 10 = 71 x 3) is the Type II Error for B's access code. After proceeding in a similar fashion for E, F, and H, the average Type II Error may be computed. In Figure 4-5, we present the Type I and II errors which resulted from a simple strategy of using the same rejection threshold for all 25 subjects in the design group. The results are shown in tabular form at the bottom. One subject's test data was poorly reproduced on the copier. It was therefore eliminated leaving only 72 Type I attempts. Also, for 20 subjects, only 9 copies were made of design data, for the 5 remaining subjects, 10 copies were made. Thus, the resulting Type II attempts amounted to 10773, as given in Table 4-1. The graph at the top of Figure 4-5 provides a plot of the tabular results.

The results presented in Figure 4-5 for the Type I Error rate were unsatisfactory. In investigating these results, it was discovered that some of the 25 design sets clustered significantly better than others did. With at most ten nine-dimensional vectors in each design class, the estimates of the mean vector and covariance matrix are at best rudimentary; a deviation in any vector component will change these estimates by a non-negligible amount. Using the same threshold for each class, then, does not achieve the best possible performance. Consequently, a new strategy was employed - a variable threshold with class. Choosing the threshold from the range (4, 10) that minimizes the number of Type I Errors for each class yields the statistics shown in Table 4-2. The average Type I Error is 1 out of 72 attempts for 1.4%; the average Type II Error is 177 out of 10773 attempts for 1.64%.

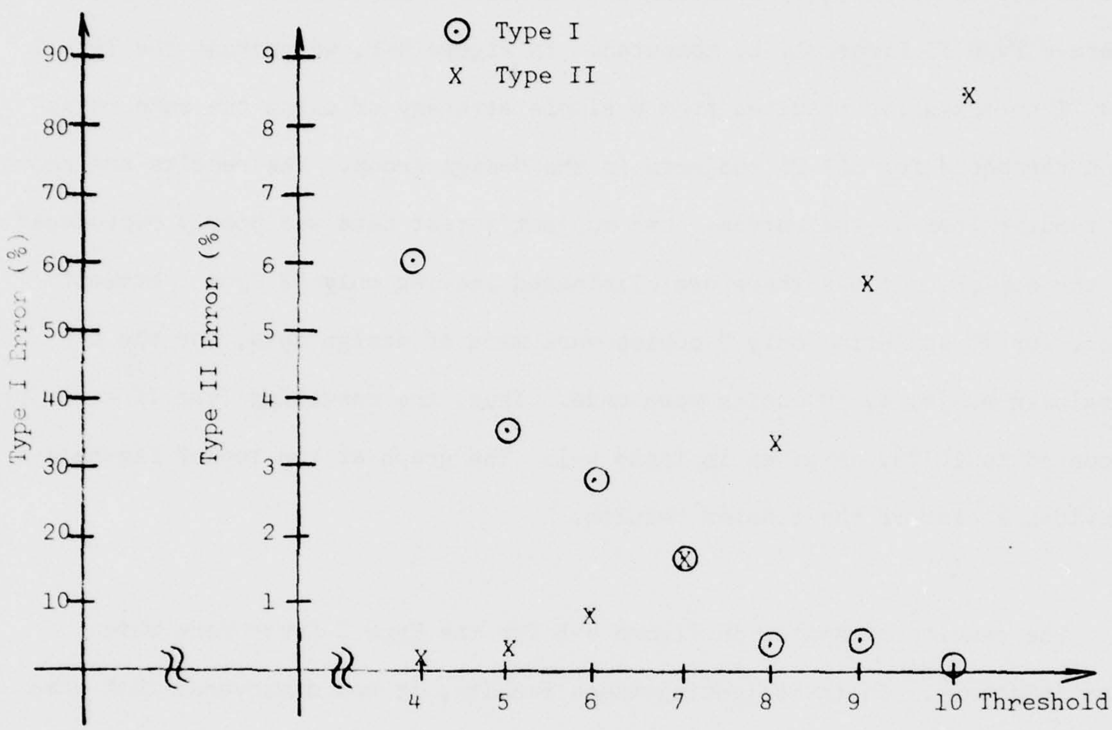

Figure 4-5 Error Rates For Uniform Threshold

THRESHOLD	TYPE I ERRORS Out of 72 Attempts		TYPE II ERRORS Out of 10773 Attempts	
4.0	44	61%	16	.15%
5.0	26	36%	43	.40%
6.0	20	28%	103	.96%
7.0	13	18%	184	1.7%
8.0	3	4.2%	368	3.4%
9.0	3	4.2%	627	5.8%
10.0	1	1.4%	927	8.6%

Table 4-1 Error Rates For Uniform Threshold

CLASS	THRESHOLD	TYPE I ERRORS	TYPE II ERRORS
1	4.	0	0
2	5.	0	0
3	5.	0	0
4	5.	0	0
5	5.	0	0
6	6.	0	0
7	5.	0	2
8	7.	0	0
9	7.	0	0
10	8.	0	12
11	10.	0	3
12	10.	0	26
13	8.	0	0
14	8.	0	6
15	4.	1	0
16	8.	0	29
17	8.	0	3
18	8.	0	46
19	5.	0	2
20	8.	0	33
21	7.	0	1
22	5.	0	12
23	5.	0	0
24	8.	0	1
25	4.	0	1

Table 4-2 Variable Threshold Statistics

Even the best performance of certain classes as shown in Table 4-2 is below average; notably classes 10, 12, 16, 18, 20 and 22 for their Type II Errors, and class 15 for its Type I Error. In an attempt to explain such behavior, consider Table 4-3. Listed in Table 4-3a are the average variances over all 25 classes for each measurement, and a ranking of these variances from highest to lowest. Table 4-3b lists all classes that have a variance of any measurement greater than the arbitrary value of 200. Notice that in almost all cases the measurements listed in Table 4-3b have the worst average variances. In addition, the seven different classes listed are precisely those classes which caused the greatest number of errors (Table 4-2).

It is extremely important to identify the cause of the poor performance for some subjects. A study has indicated that there are three sources for the large variances in classes 10, 12, 16, 18, 20, and 22. In decreasing order of importance, the error sources were (1) the technicians performing the manual marking of the handprint copies failed to follow their instructions, (2) the copier produced a poor image, one subject to extensive mottling and loss of entire areas, and (3) two of the subjects failed to press their hands flush against the copier surface. Of these errors, only the latter need concern us since human inconsistencies will be removed once automatic feature extraction techniques are employed and the copier will be replaced in the actual system by some type of television tube or scanner. The third error source simply instructs us that some mechanism must be provided in the final access system to ensure that the subject's hand is maintained flush with the optical system image plane.

Measurement	Average Variance ($10^{-2} mm^2$)	Ranking
1	71.1	3
2	14.6	8
3	11.1	9
4	125.	1
5	42.5	6
6	66.5	4
7	47.9	5
8	37.9	7
9	74.9	2

Table 4-3a Average Variances for Each Measurement

Variance	Class	Measurement
619.	20	6
567.	10	1
456.	22	4
349.	12	4
318.	18	9
284.	22	5
225.	20	5
215.	15	4
213.	16	6

Table 4-3b Worst Individual Variances

4.2. CARDIOGRAMS

In contrast to the handprint, the cardiogram tracings require more extensive processing. However, each step in the processing sequence is automated to the extent that the software required for an automatic verification system can be written with minimum effort. The features selected are simply defined and extracted from each heartbeat, yet the error estimates obtained are quite encouraging.

4.2.1. Preprocessing

A significant quantity of data is required to perform a meaningful error analysis so, to use the collected data to its fullest extent, each individual heartbeat is considered to be a single event. One feature vector is obtained then from one heartbeat. This philosophy precludes the possibility of using such features as rhythm and rate for this study. In any subsequent work and particularly in a dedicated verification system, such features may be exploited to increase performance. The feature extraction algorithm presented in Appendix E is designed to operate on a single beat. To minimize program complexity the algorithm also assumes a relatively smooth waveform. The preprocessing prepares the data for the feature extraction.

One basic method to low pass filter the waveform is to convolve it with a window function. The simplest window is a rectangular one, and Figure 4-6 shows the result of such a convolution. Note also that the waveform has been resampled by a factor of 2, since it was originally oversampled. Other

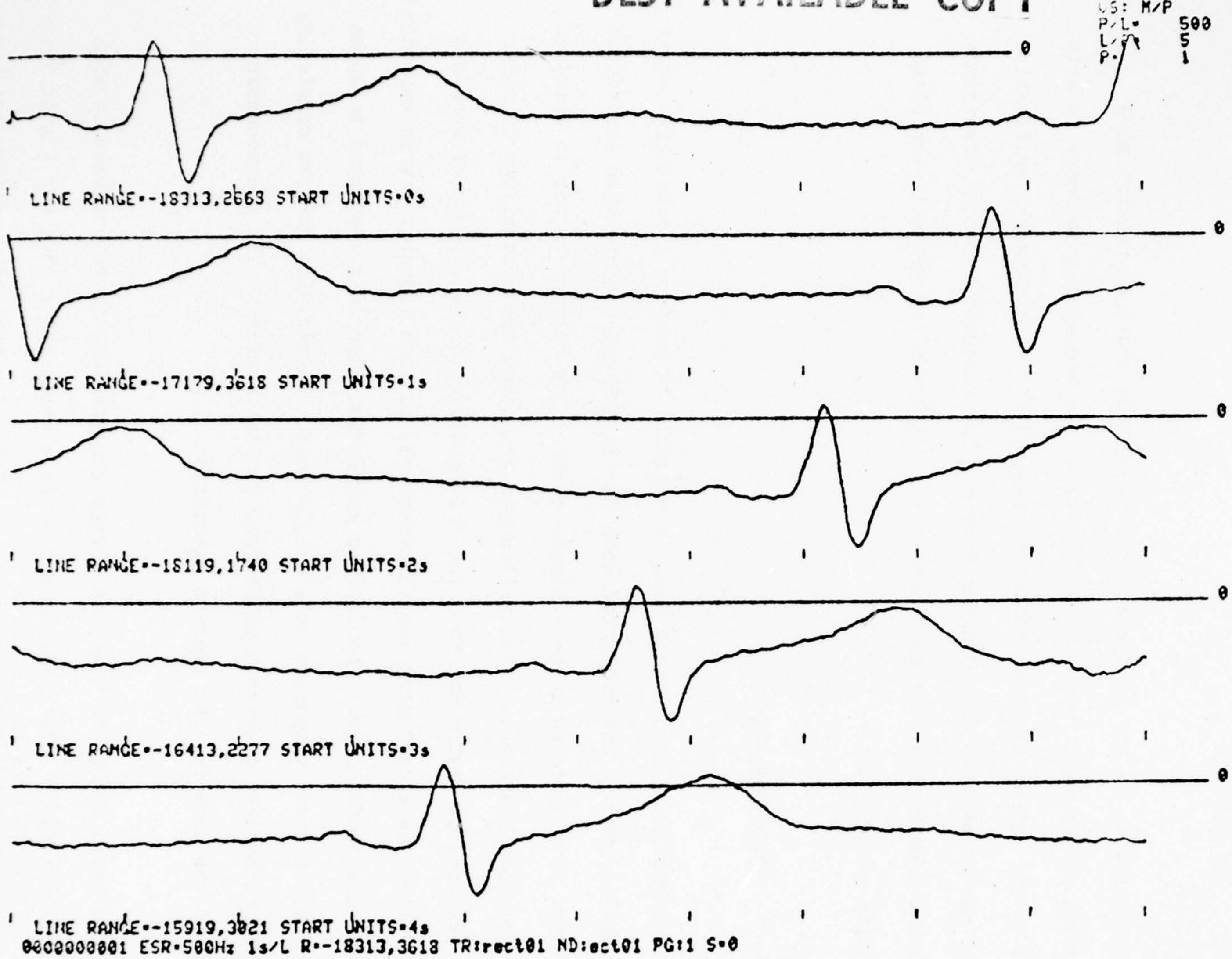

Figure 4-6 Smoothed Cardiogram Data

windows and more complicated smoothing techniques were compared with the rectangular window, but none were found that performed so much better as to warrant their added complexity. Figures 4-7 to 4-10 show four attempts at using a digital filter to smooth the data in Figure 5-5.

The segmentation is accomplished by triggering on the use time of the leading edge of the distinctive, quite sharp QRS complex as shown in Figure 4-11. When a complex is located, pointers are placed at the proper time intervals both before and after it, resulting in the separation of that heartbeat from the long record. After the entire record is searched and all the heartbeats have been separated, the features can be extracted.

4.2.2. Feature Extraction

The main characteristics of the heartbeat are described in Section D.7. Because we define a feature vector from one beat only and because we measure electrical potential in only one configuration, many of those characteristics are unusable. A large unmanageable number of features can be defined from almost any waveform (e.g., each sample value can be a feature). Thus we cannot initially define a large feature set with the intent to reduce the number of features later, especially since we wish to keep the complexity of the feature extraction algorithm to a minimum. Only a few features were defined at first, and gradually the present set of ten features was decided upon by careful study of distinctiveness of waveforms. The features include the five time intervals and the five amplitude differences between adjacent pairs of the six points shown in Figure 4-12. Table 4-4 lists the ten

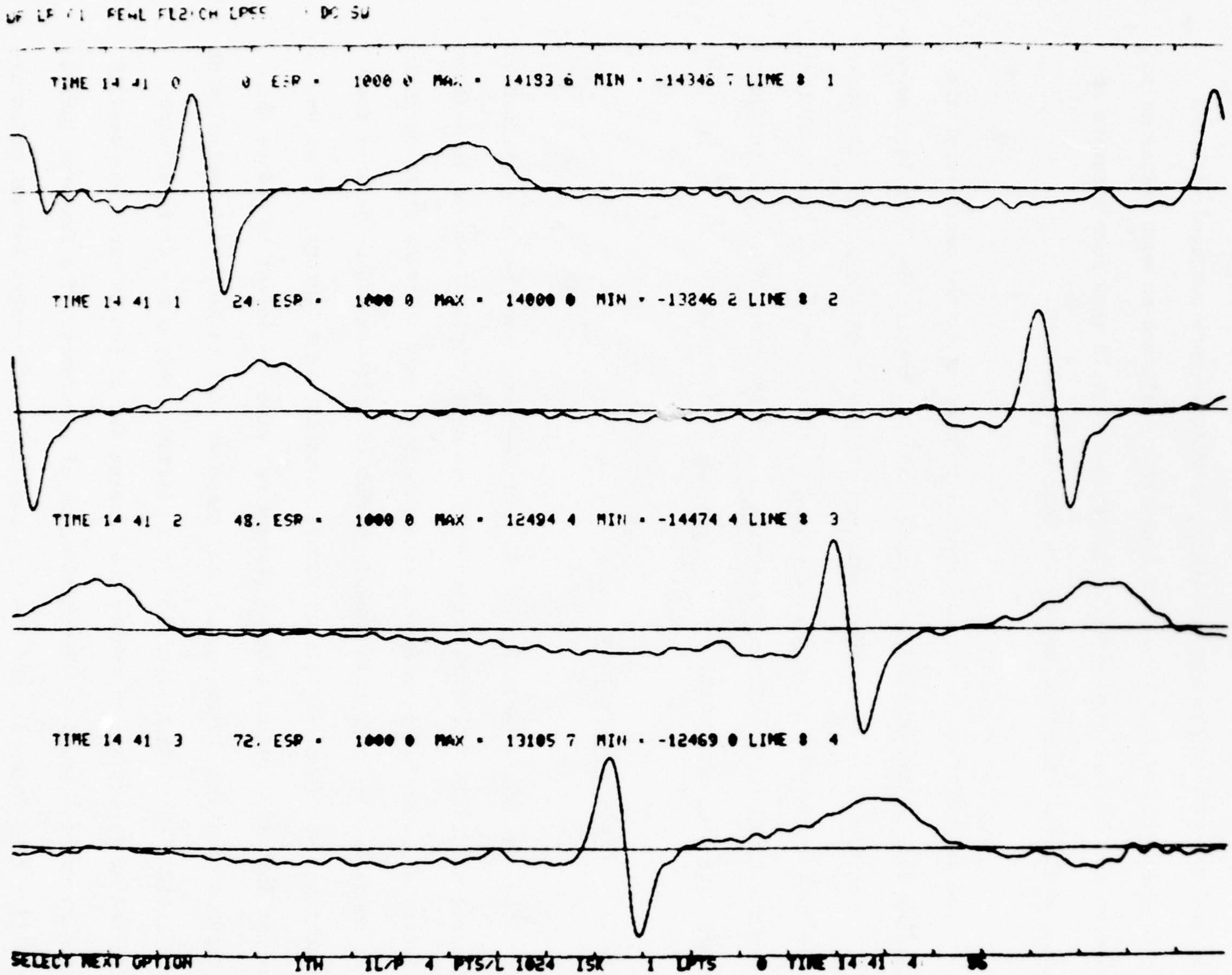

Figure 4-7 Chebyshev 8-Pole Filter, Low Pass, Cutoff Frequency 55 Hz.

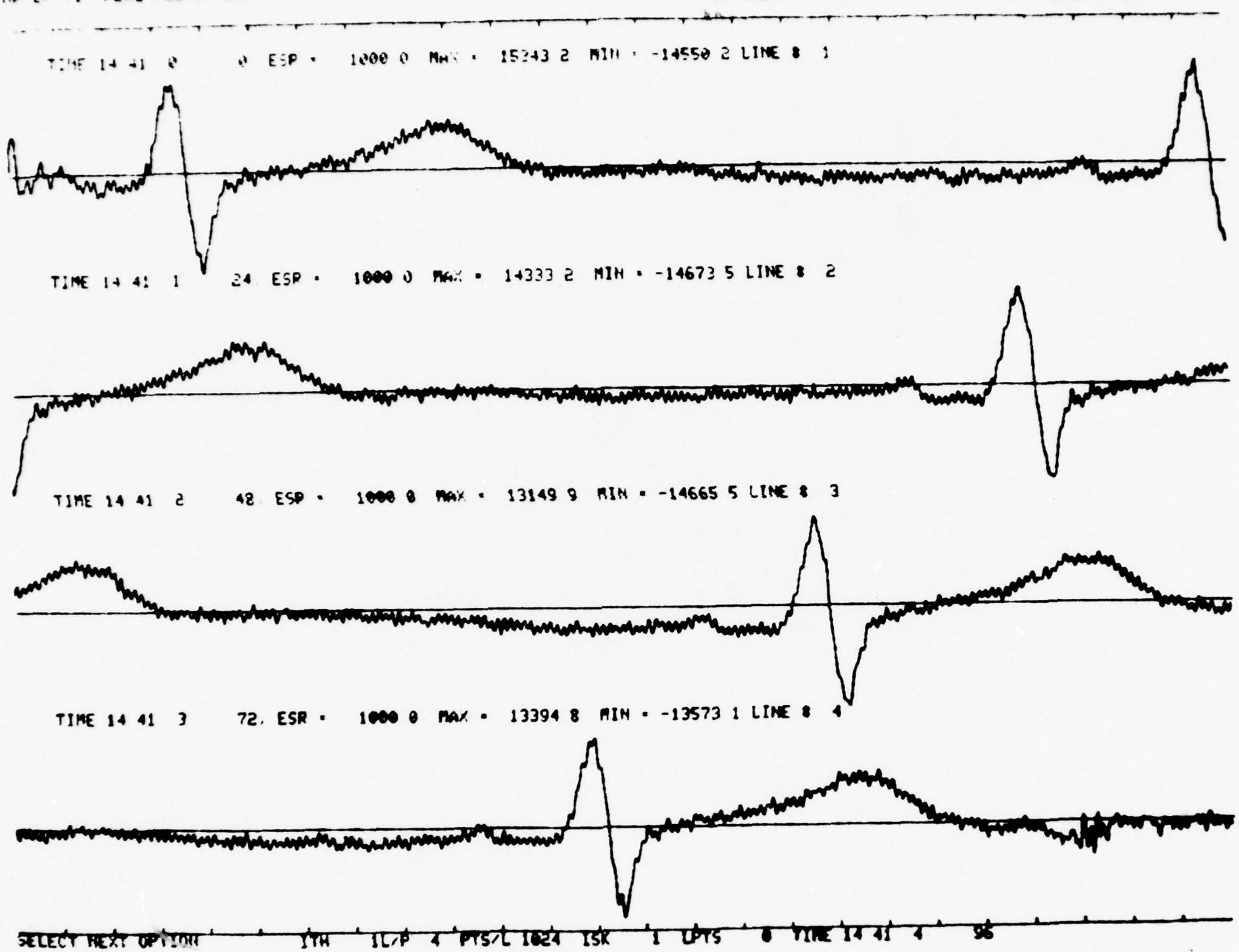

Figure 4-9 Chebyshev 8-Pole Filter, Band Elimination, Band Limits 55-65 Hz.

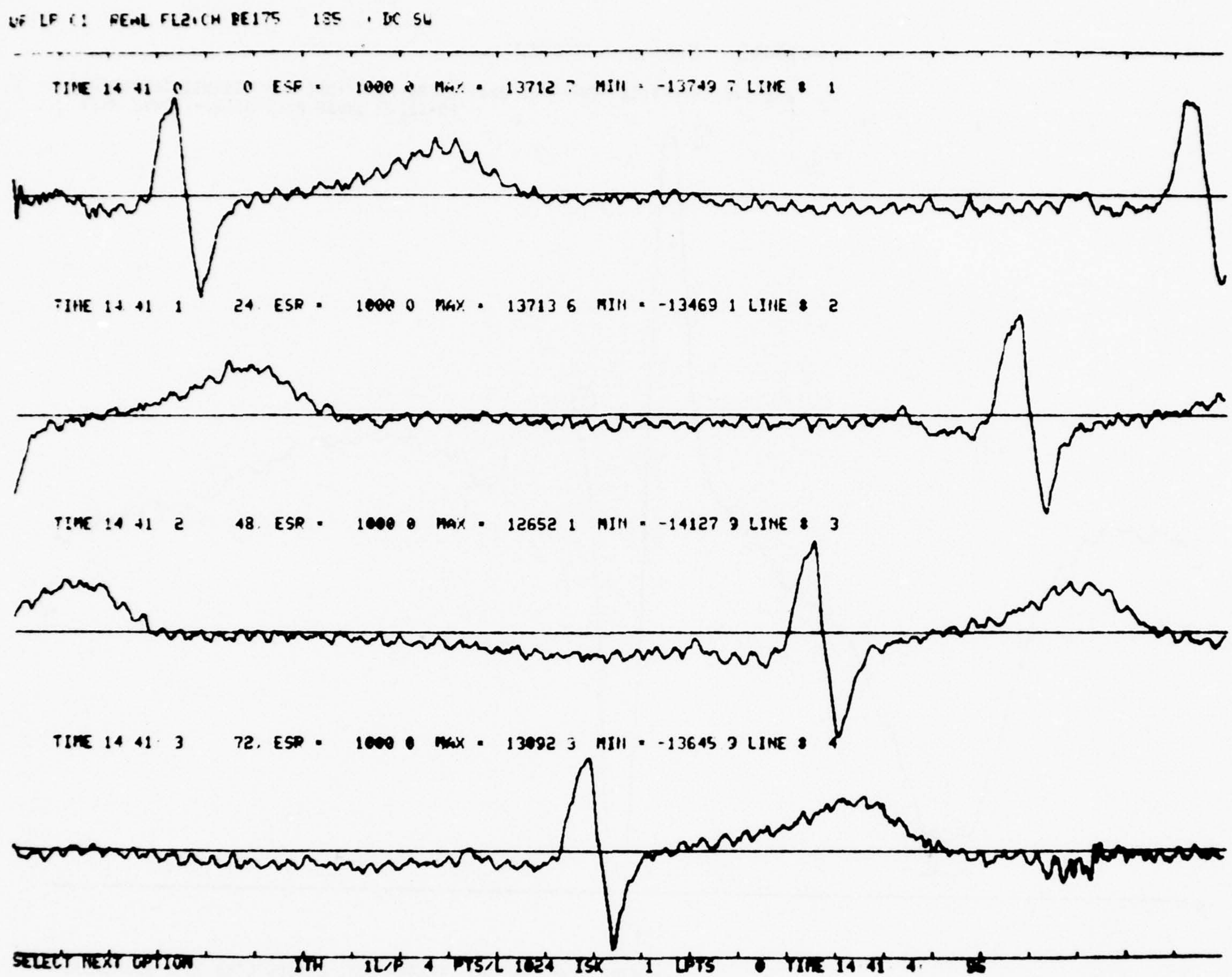

Figure 4-10 Chebyshev 8-Pole Filter, Band Elimination, Band Limits 175-185 Hz.

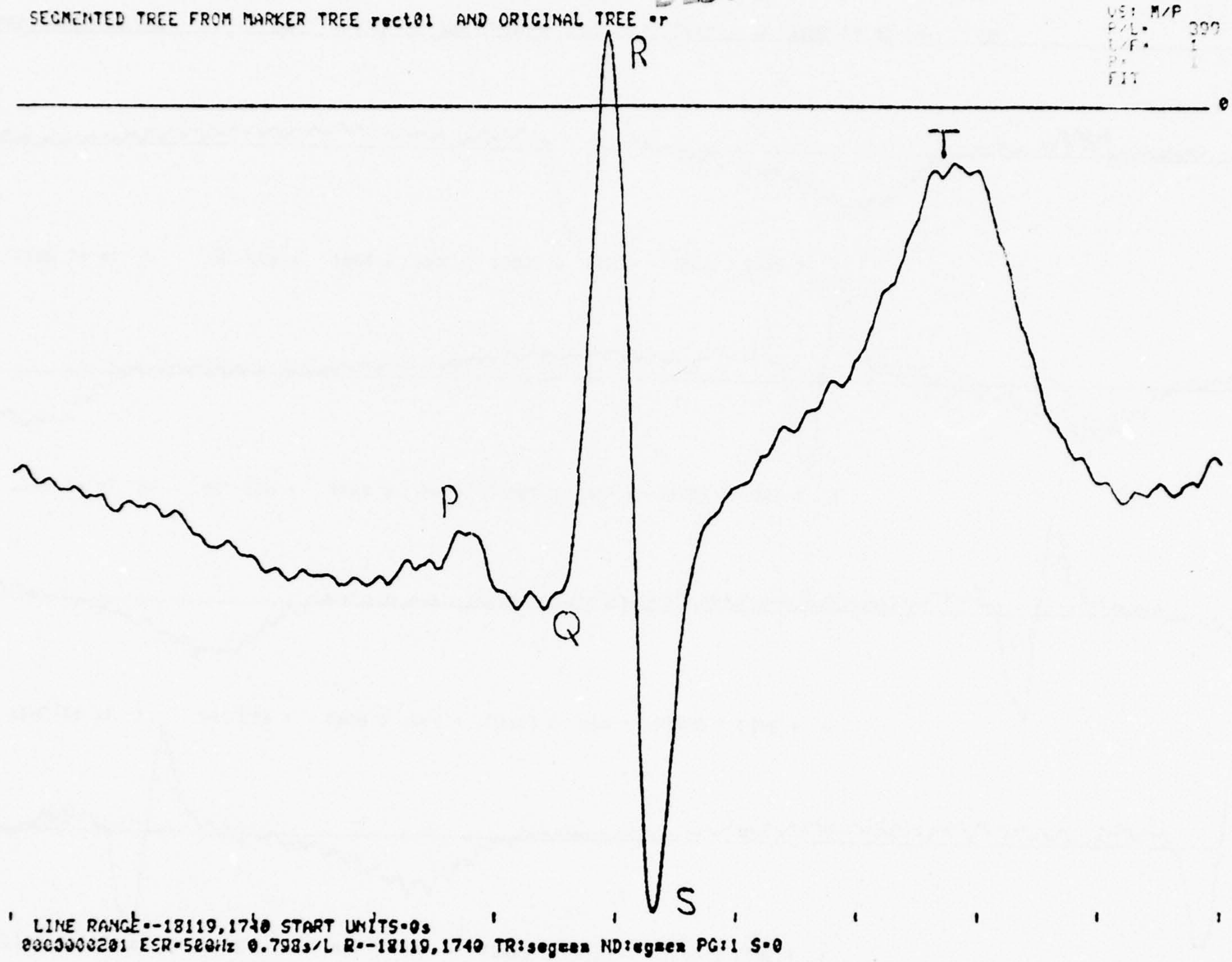

Figure 4-11 QRS - Complex

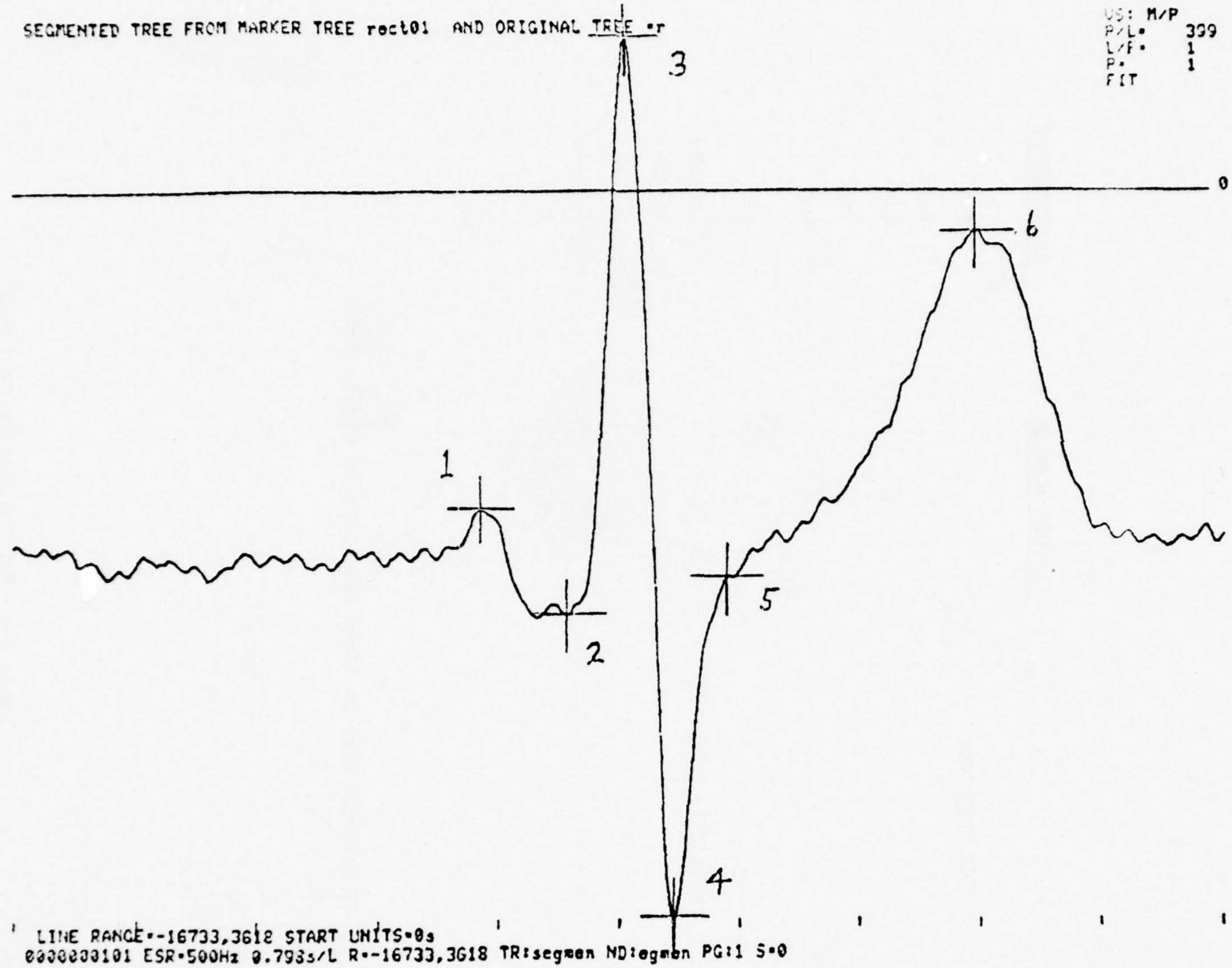

Figure 4-12 Ten Cardiogram Feature Fiducial Points

	FEATURE NUMBER	MEASUREMENT*
TIME FEATURES	1	2-1
	2	3-2
	3	4-3
	4	5-4
	5	6-5
AMPLITUDE FEATURES	6	(1-2)/(3-4)
	7	(3-2)/(3-4)
	8	(6-5)/(3-4)
	9	(5-4)/(3-4)
	10	3-4

*Numbers refer to those depicted in Figure 4-12.

Table 4-4 Ten Cardiogram Features

features in the form used in the logic evaluation. Note that four of the amplitude features are normalized to the difference (3)-(4), so only measurement 10 is an absolute amplitude. The PARLAN routine EKG presented in Appendix E extracts these 10 features, one feature vector from each heartbeat.

4.2.3. Logic Design and Evaluation

The feature vectors are analyzed in a manner very similar to that for the handprint vectors. In the entrance scenario, an applicant requesting access to a restricted area inputs a password to the system, indicating his assumed identity. The system now reads several heartbeats of the individual, performs the necessary processing to extract the features, and averages the feature vectors together. This one average feature vector is then compared to the mean vector of the identity class previously determined by the applicant's password, and an accept or reject is made.

Note that unlike the handprints, the final decision here is based on an average of several feature vectors. The electrical activity of the cardiogram changes appreciably in short time frames (respiratory cycle being a primary cause), and the averaging operation minimizes this noise and, with higher reliability, obtains a typical feature vector. To give an indication of these changes Appendix F shows ten heartbeats from the same person taken on the same day. To compare this intra-individual variation to the variation from person to person, Appendix G contains one heartbeat from each of the thirty people in the data set. Handprints, on the contrary, are quite stable in time, so no

averaging is necessary. Like the handprints, Nearest Mean Vector logic is used for classification, but the metric is the Mahalanobis [2] distance. Thus we require the covariance matrix of the design class.

Since the processing of the cardiogram data is performed automatically, some mistriggers invariably occur, creating feature vectors that are unlike the norm. To delete these atypical vectors the data is presented to a simple clean-up algorithm. Because of the way in which the features are defined (Figure 4-12), each component of each vector must be a positive number. We therefore delete any vector with a negative component. This method can be expanded by relying on the medical literature to provide tighter bounds for all ten measurements. The algorithm simply deletes a vector with any component falling outside the specified range for that measurement.

The results for both Type I and II error estimates are shown in Figure 4-13 and Table 4-5. To evaluate the Type I error, the data was evenly divided into a design set and a test set. The individual design sets were used to obtain class means and covariances; the test set vectors were averaged in groups of ten and these average vectors applied to the design logic. The results of each class were combined to yield an overall Type I error estimate. Because of the small amount of available data, the Type I error rate can be estimated to at most $\pm$ 1%. More data is required to show the true shape of the curve.

The Type II error is based upon each entire class in turn serving as the design set, and all other classes as the test set, again averaging each group

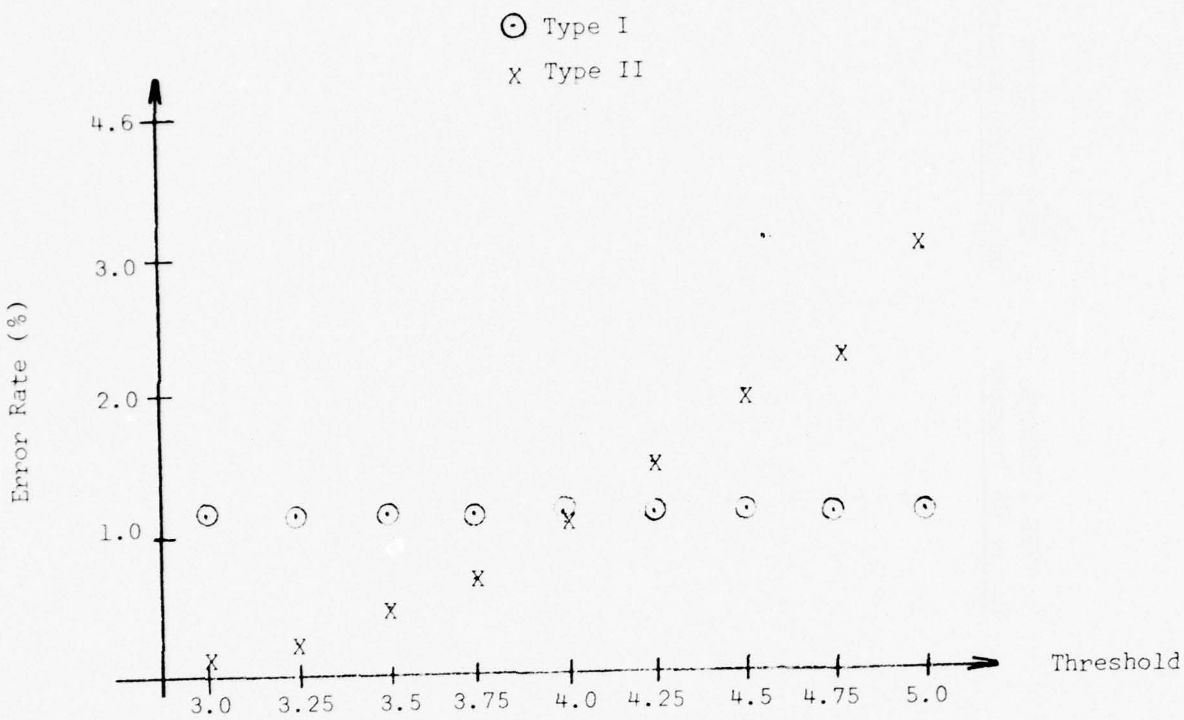

Figure 4-13 Cardiogram Error Statistics

THRESHOLD	TYPE I ERRORS Out of 83 Attempts	TYPE II ERRORS Out of 4785 Attempts
3.0	1	8
3.25	1	11
3.5	1	23
3.75	1	33
4.0	1	51
4.25	1	72
4.5	1	96
4.75	1	109
5.0	1	142

Table 4-5 Cardiogram Error Statistics

of ten vectors to obtain one test vector. The results for each class are combined to determine the overall Type II error estimate. Note that each group of ten vectors is used N-1 times as a test attempt, where N is the number of "admissibles" (here, N=30). As expected, the Type II error rate increases as the threshold boundary increases. Because of the uniform Type I error over the indicated thresholds these graphs show that for the cardiogram data analyzed, a dedicated system can operate with a threshold as low as 3 and perform under the required specifications. However, a threshold of 4 is probably a more realistic one based on the statistical results of Appendix B. Thus, we estimate Type I Error rates at 1.2% and Type II at 1.1%.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

The purpose of this research was to select two promising physical attributes for in-depth investigation to determine their potential use in identity verification systems. Both attributes selected show excellent promise. For convenience we summarize in Table 5-1 the Type I and II error rates obtained in Section 4.

Before considering the conclusions which can be drawn from Table 5-1 it is useful to review a few key points in the data processing and analysis. The electrocardiograms were collected in a manner which attempted to duplicate as nearly as possible the envisioned access system. The data was collected with the subjects standing, without a ground electrode, with no electrode paste, and with electrodes attached to the index fingers. Furthermore, the data was processed almost entirely automatically. For example, automatic segmentation and feature extraction were applied in order to obtain the results of Table 5-1. This software could easily be moved into a test-bed system. Thus, we have confidence in the C-trace results of Table 5-1 and feel they represent error rates which could be obtained in the field. Furthermore, the equipment which was used in the data collection and analysis of this study is reasonably close to actual equipment of a test-bed system. Thus, it appears that an access control system utilizing electrocardiograms could be produced at a reasonable

Error Type / Attribute	I	II
Handprints	1.4%	1.6%
C-trace (ECG)	1.2%	1.1%

Table 5-1 Error Rates for Attributes Studied

per unit cost. On the other hand, although the error statistics of the C-trace can undoubtedly be improved, it is the authors' opinion that a Type I error of 1% and a Type II error of .1% probably represent the ultimate performance of the system. This opinion is based on the observation that most of the information content of the ECG is already being extracted. All improvements will probably come from quantitative improvements, not qualitative ones.

One important point about electrocardiograms which has not been touched on elsewhere is the fact that the waveform shows second-order variability as a function of heart rate. The encouraging results of this study were obtained with no special consideration given to this problem. However, in the system we envision, the variability with heart rate would be compensated. We propose to (1) store approximately three records for each individual, each representing different heart rates, and (2) to measure the subject's heart rate at each entry attempt in order to retrieve either the appropriate record or an appropriate interpolation.

The handprints, conversely, we believe to be almost open-ended in their ultimate error statistics. First of all, as discussed in Section 4.1., the hands chosen for study were those most similar to one another. Thus, the Type II error rates are on the pessimistic side. More importantly, in the handprint feature extraction discussed in Section 4, we have only utilized a miniscule fraction of all the available lines and creases. The major lines of the palm are used only for deciding where on the palm its breadth is to be measured, whereas the minor lines of the palm have not been used at all.

Because of the manual steps which were employed in the feature extraction performed on the handprint copies, however, we must consider that, at this time, we have only demonstrated that handprints contain the necessary richness of detail to provide the required Type I and II error rates. It remains to be shown that handprints can be digitized and submitted to automatic feature extraction. A small effort was undertaken to demonstrate that even a general purpose digital TV camera and general purpose image processing algorithms could produce an image from which measurements could be automatically extracted. The results, described in Appendix H and shown in Figure H-1, are quite encouraging. The finger crease lines and the finger silhouette, on which most of the measurements employed in this study were based, are quite well defined in Figure H-1. Notice that even the writer's callous on the second finger is visible, indicating that the subject is right-handed. Furthermore, we expect that more specialized image processing software, designed for this particular job, will achieve significantly better results.

Finally, we would like to point out that the two attributes chosen for study complement each other nicely. The C-trace we believe to be of lower cost and of lower (ultimate) performance in error rates. The handprint will probably require more development, and access control by this method will be of higher per unit cost, but its performance can, we believe, be improved to almost any level desired.

5.2. RECOMMENDATION

Based on the conclusions of the previous subsection, we recommend that development of both personal attributes be continued. Both are ready, we feel, to advance to a "test-bed" stage. In the test-bed stage we would build the complete software package for automatic digitization, preprocessing, feature extraction, post-processing, and comparison with stored data. The output would be a decision in near real time that the individual's identity was or was not verified. This software would be installed in suitable hardware to permit a real time extraction of the physical attribute measurements. We now discuss the equipment configuration which would be necessary and how the test-bed system would be used.

5.2.1. C-Trace Test Bed

The test bed for the C-trace would employ the Hewlett-Packard 1500B electrocardiograph (used in the data collection of Section 3) as its transducer. The signal processor to implement the logic would be a mini-computer with analog-to-digital converter (ADC), digital-to-analog converter (DAC), terminal, and cartridge disk drive. This configuration is shown in Figure 5-1. The signal output of the electrocardiograph would be digitized at the ADC and processed by the computer. The computer is also in a feedback loop to determine the DC bias (Section 3.2.) and compensate by tuning the amplifier through the DAC. A terminal is provided for program control and to permit the entrant to identify himself to the system. The disk serves as bulk storage

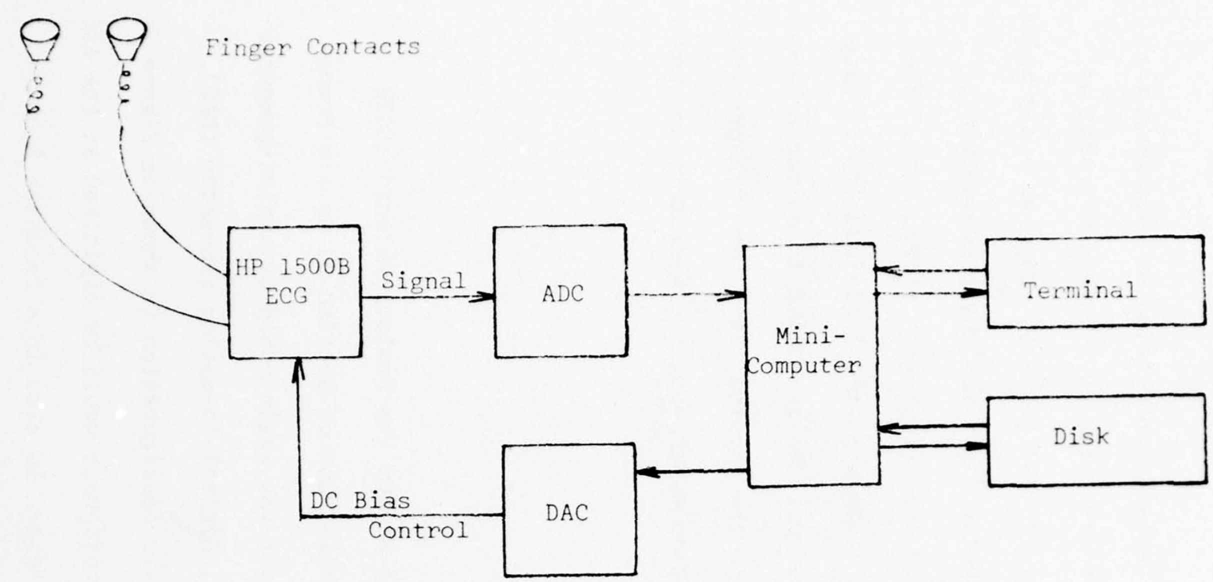

Figure 5-1 Test Bed Configuration for the C-Trace (ECG)

and also permits programs developed on larger computers to be loaded into the test bed computer.

The software would constitute a complete access control package. The subject would identify himself by means of the terminal, and insert his index fingers in the contacts. The cardiogram would be processed to obtain measurements which would be compared to the subject's identity record. A decision would be made and the new record and results stored. Statistics would be compiled. Also, the software would perform the operations necessary for entering a new subject's file into the records.

The preprocessing and feature extraction algorithms would at first be essentially identical to that described in Section 4. The test bed could be installed at the PAR facility in a high traffic area. A list of legitimate entrants and intruders would be formed from the personnel who frequently pass by the test bed. Since processing would proceed in near real time, statistics could be rapidly accumulated. However, we do not feel our present algorithms are optimal. Consequently, after the system of Figure 5-1 is operational, the first task would be to explore modified algorithms. The testing of these would advance rapidly due to the daily monitoring of performance statistics. Once the algorithms reached a satisfactory level of performance, modifications would cease and extensive statistics would be compiled. Thus, the test-bed study would consist of three phases: (1) configure hardware and software, (2) modify algorithms to enhance performance, and (3) gather statistics on performance.

The logical next step, assuming adequate results with the test-bed system, would be brassboard development with actual components to be employed in the final system. At this time there is every reason to believe that the processing needs at the brassboard stage can be adequately served with a microprocessor, a fact which will greatly reduce final per unit cost.

5.2.2. Handprint Test Bed

We recommend that the test bed for the handprint be implemented on the RADC DICIFER system. This image-processing system contains a digitizing television camera in addition to a processor and a full complement of peripherals. It would only be necessary to build a jig for positioning the hand. This jig would probably also contain the lighting required by the camera.

The same three development stages described in Section 5.2.1. would also apply to the handprint, with three exceptions. First, feature extraction software would need to be developed. Second, RADC personnel would serve as subjects. Third, since the DICIFER television camera would not be employed in an actual system, we recommend a small task to study possible imaging devices. We feel that the existence of a complete image processing system will speed the development of a handprint identity verification system.

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APPENDIX A

PERSONAL ATTRIBUTES PRELIMINARY STUDY GUIDELINES AUTHENTICATION TECHNIQUES

A.1. OVERVIEW

We are about to begin Phase I of the personal attributes verification (PAV) contract. Phase I is an examination of a wide variety of potential attributes. The various attributes will be assigned to individuals for preliminary study on the basis of the individual's interest, expertise, and availability. The two most promising attributes will be evaluated through data collection and OLPARS tests in Phase II. Engineers who will be working on this contract but were not involved in preparation of the proposal should read the Statement of Work and the first monthly report.

A.2. PERSONAL ATTRIBUTES TO BE CONSIDERED IN PHASE I

For the purposes of the proposal, we divided the attributes into three categories depending upon whether the attributes were associated with the hand, head, or other part of the body. Table A-1 lists the attributes to be considered.

A.3. EVALUATION CRITERIA

Although the personal attributes in Table A-1 were organized according to their relation to the parts of the body examined, another useful breakdown is

	Feature/Attribute	Engineer(s)	Hours Available	
	Hand			
1.	Palm prints	GF, FF, DS	60	
2.	Finger folds	GF	30	
3.	Finger lengths/area	GF		(see 2.)
4.	Color	GF		(see 18.)
5.	Venous patterns	DL	40	
6.	Plethysmograms	MN	30	
7.	Skin resistance	MN, JW	10	
8.	Total resistance	DL		(see 28.)
9.	Bone pattern (ultrasound)	RE	20	
10.	Tremor pattern	JW	10	
11.	IR radiation pattern	DL		(see 5.)
12.	Nail strictions	RE	10	
	Head			
13.	Eye scan path/dilation	GF	20	
14.	Eye color	GF	20	
15.	Sonic charact. teeth/skull	RE	10	
16.	Bite patterns	FF	20	
17.	Ear structure	FF	30	
18.	Hair color, etc.	GF	10	
19.	Electroencephalograms	MN	20	
20.	Lips	NA	10	
	Miscellaneous			
21.	Footprints	X	10	(see 1.)
22.	Saliva	NA	10	
23.	Blood composition	GF	10	
24.	Odor	NA, MN	20	
25.	Height, weight....	MN	20	
26.	Gait	NA	10	
27.	Electrocardiograms (ECG-30, BCG-10, PCG-20, DCG-10)	MN	70	
28.	Verbal responses		50	
	personal history	JM		
	response pattern	JM		
	typing style	JW		
29.	Magnetic response of... and fillings	DL	10	
30.	Polygraph	NA	20	
		Total =	580	
	Comparative appraisal & eval.		60	
			640	

Table A-1

to categorize the attributes in terms of their complexity into "scalar," "vector," and "tensor" groups. A scalar attribute is a single number, a vector attriubte is a set of numbers which are easily expressed in monoparametric form, while a tensor attribute requires two or more parameters for adequate representation. Height and weight are scalar attributes, waveforms such as EEG's are vector attributes, and complex quantities such as palm prints and blood composition are tensor attributes. From the vector and tensor attributes we shall have to define features. In general, one can say that the more complex attributes will be the richer in detail and hence the probability of defining unique features is high. However, the problem of digitizing the feature will be severe (thus costly). The scalar attributes need no feature definition, obviously, and many of them can be easily, reliably, and inexpensively transduced. Individual uniqueness, on the other hand, will probably be quite low. Eventually we may want to assemble unrelated scalar attributes to form a feature vector which will have a high degree of uniqueness.

We will evaluate attributes in six categories. In each category, the attribute will be rated by the researcher on a scale from zero to one hundred. Attributes scoring fifty or less in any category will be eliminated. The remaining attributes will be evaluated by taking a weighted sum of their scores in the various categories.

The categories are as follows:

1. Separability. Is the personal attribute rich enough and repeatable enough to identify individuals? We shall be interested in both Type

I (rejecting individuals on the acceptance list) and Type II (accepting individuals not on the list). These error rates are inversely correlated, so for the purpose of this evaluation we shall fix Type II errors at 2% and evaluate only in terms of Type I. The score of an attribute will then be 100 minus (an estimate of) its Type I error rate.

2. Acceptability. Will the method of measuring the attribute be acceptable to the users? The researcher should explain how the attribute will be measured. Then a survey will be made to determine user acceptance.

3. Technological Feasibility. Here simplicity will be important. Evaluation should proceed on these points:

a.	Is equipment now available?	(100)
b.	Could the equipment be made with a small modification of available equipment?	(90)
c.	Large modification?	(80)
d.	Is new equipment required?	(60)
e.	Can no equipment be imagined?	(50)

4. Cost. In the cost category we distinguish three areas.

   a. Development costs. Especially important here is the cost to collect data for the Phase II evaluation of the attribute. For

example, to measure an attribute might require a very expensive piece of equipment. Since we have to collect new data for Phase II, this would appear as a development cost to us.

b. Purchase cost.

c. Operating cost.

5. Speed. Our goal is a process which accepts or rejects an individual in 5^s. Scoring in this category should be based on

60^s	(50)
30^s	(75)
15^s	(90)
5^s	(100)

6. Penetrability. How easily is the system fooled? Think in terms of a trained agent attempting to penetrate the system. Evaluation should be based on the <u>cost</u> to an intruder to penetrate.

It is obvious that to evaluate an attribute in the above categories one must envision a working system. How will the attribute be measured? To guide our thinking we have agreed on the following configuration. The subject in question desires access to a controlled room. At the entrance is located an "identity lock." The subject steps into the lock and closes a door behind him. The attribute is tested and, if the subject is identified as a member of the acceptance set, a second door opens to permit access. We imagine for the purpose of the evaluation an acceptance list of 300 persons.

A.4. FORMAT FOR REPORTING RESULTS

Each person assigned a topic will assume an advocacy role in support of his attribute. The evaluation committee will assume an adversary role.

In order to save time later, each researcher's results should be written up in a form essentially suitable for the final report. The history of the identification technique/attribute should receive perhaps a paragraph. Because of the fact that any technique will be eliminated for a score of 50% or below in any category, the weaknesses of a technique should be examined first. If a technique can be eliminated in one category, there is no need to continue research into the other categories. All conclusions must be documented. List references in accepted fashion.

A.5. PROCEDURE

Instructions:

1. Review the list of attributes to see what attribute has been assigned to you and note the alloted time. These times include all general review and writing time.

2. Note any attributes for which you might have leads, references, thoughts, or sources even though they are not assigned to you, and see the responsible engineer.

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PERSONAL ATTRIBUTES AUTHENTICATION TECHNIQUES.(U)
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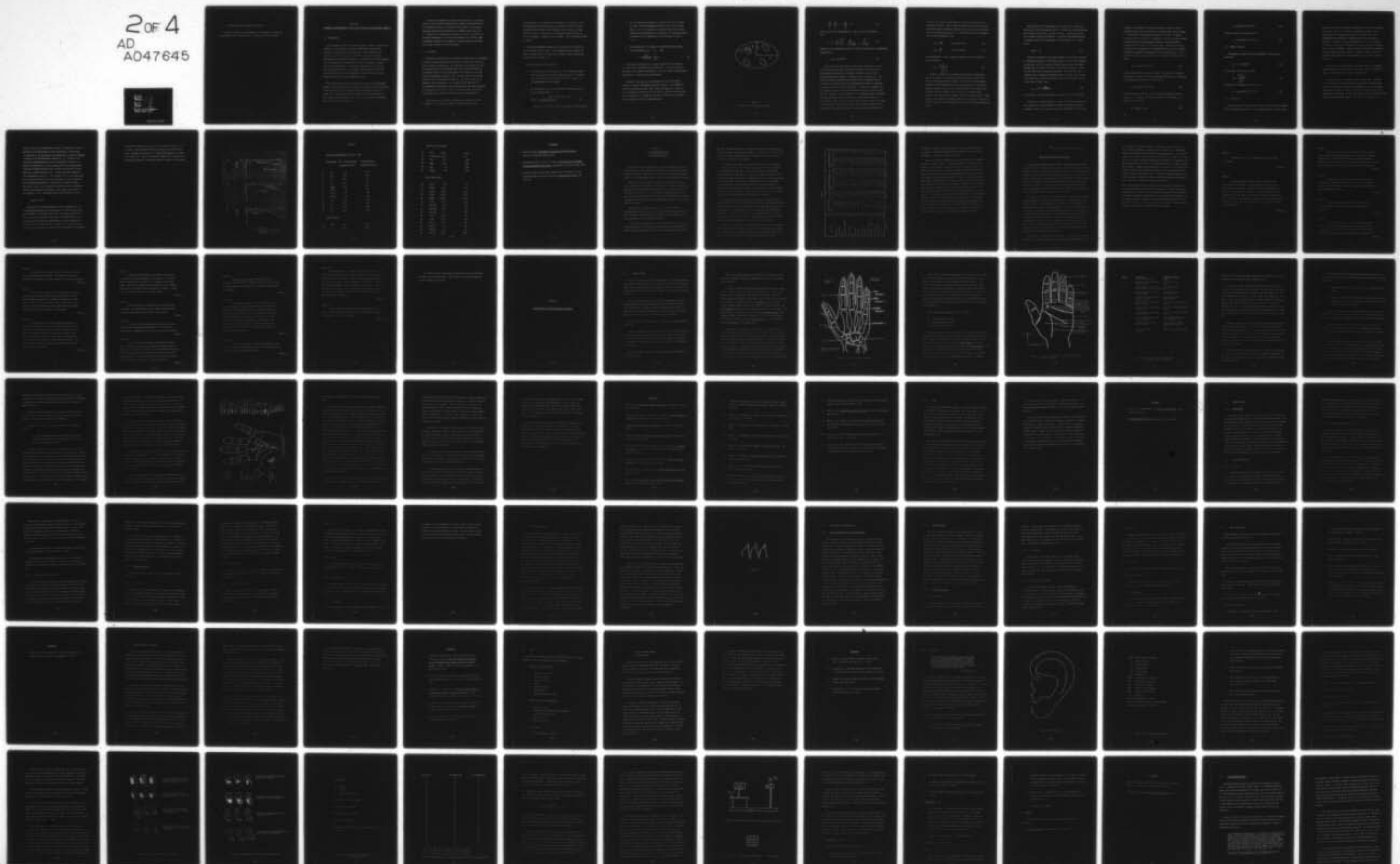


3. Complete research and report in four weeks.

Note that a good source of information is a statement by an expert (in the pertinent field of physiology, etc.) obtained by writing a letter.

APPENDIX B

PARAMETRIC CONSIDERATIONS OF TYPE I AND II ERRORS IN THE FINGERPRINT PROBLEM

B.1. INTRODUCTION

The fingerprint problem is a particular type of pattern classification situation. Given a large population of individuals, some personal attribute is measured on a day-to-day basis. This attribute should remain more or less constant for a specified individual and should distinguish him from other individuals. In pattern classification language, all the "fingerprint" measurements ever taken on individual A comprise class A, the fingerprints of individual B comprise class B, and so on. The classification problem is to separate all the groups (individuals) and, presented with a set of fingerprints, to decide to which, if any, of the known individuals the fingerprints belong.

The entry access problem is essentially a variant of the fingerprint problem. From a large (and for all practical purposes infinite) population, P, one is given a set of N individuals who are permitted access to a secure area. Being confronted with a member of P drawn at random, one must recognize the individual if he is one of the N licensed individuals and one must reject him otherwise.

In either the fingerprint or entry access problem it is frequently useful to have a priori estimates for the richness and distinctness of the identifying attribute or feature one has chosen. The following discussion derives such estimates for an extremely simple case, but it is hoped that the expressions obtained will serve to illustrate the functional dependence of the relevant parameters and to provide order-of-magnitude estimates of the worth of a specified personal attribute which might be useful in trade-off studies.

B.2. DERIVATION

We consider a population set P containing a large number of individuals. From each individual, measurements are taken to form feature vector v_i, where i denotes the individual. The individuals are measured on a day-to-day basis and due to measurement errors and intrinsic variability, the feature vector for the ith individual is not always the same, but rather is distributed according to f_i. The mean value of the feature vector for the ith individual we denote $\bar{v}_i$. The mean vectors $\bar{v}_i$ are assumed to have distribution F as i ranges over the members of P. The distribution F describes how much variation one sees from individual to individual, and we refer to this as "interindividual variability." The distributions f_i describe the "intraindividual variability."

In the entry access problem, N individuals are placed on a list of "Admits." If an individual drawn at random from P is on the

acceptance list, he is admitted, and otherwise he is rejected. Due to intraindividual variability, there is a (usually small but) non-zero probability that an Admit will be rejected. Such an error is called an error of Type I. Also, there is the parallel probability that an invalid candidate, a "Reject" will be accepted. This is denoted an error of Type II.

Under very simplifying assumptions, we would like to estimate the Type I and Type II error rates. Also, assuming that the N Admits are drawn at random from P, we shall define a number N* which measures the typical size of the Admit list.

Our assumptions are the following:

1. The vectors v_i are of dimension Λ. (The measurements which form the feature vector may be correlated, but it is assumed that Λ uncorrelated measurements may be found. Thus Λ is the dimensionality of the space.)

2. The distributions f_i are all multivariate Gaussians with the same covariance matrix Σ.

$$f_i(v_i) = \frac{e^{-\frac{1}{2}(v_i - \overline{v}_i)^t \Sigma^{-1}(v_i - \overline{v}_i)}}{(2\pi)^{\Lambda/2} (\det \Sigma)^{1/2}} \tag{1}$$

In Equation 1 "t" and "det" denote "transpose" and "determinant."

3. The classification algorithm is to decide the vector v belongs to class i when the Mahalanobis distance from v to $\bar{v}_i$ is less than k. If v is not within k of any mean vector, the vector is rejected and the candidate is not admitted. The decision surface determined by this algorithm is a hyperellipsoid of volume "δV".

4. The distribution F is uniform on a hyperellipsoid of volume V and semiaxes R_1, R_2, ... R_Λ. Thus,

$$V = \frac{\pi^{\Lambda/2}}{\Gamma(\Lambda/2+1)} \prod_{i=1}^{\Lambda} R_i. \tag{2}$$

The situation envisioned in the above assumptions is illustrated in Figure 1 for a two-dimensional feature space. The large ellipse is the bound of the uniform distribution F. The four smaller ellipses denote the decision boundaries for four individuals.

The Type I error rate E_I is the integral of f_i over all points which lie outside of Mahalanobis distance k from $\bar{v}_i$. It is easiest to compute the probability that a Type I error will not occur. With no loss of generality we can put the mean vector $\bar{v}_i$ equal to zero and carry out the integration in coordinates aligned with the axes of the hyperellipse defined by the third assumption above,

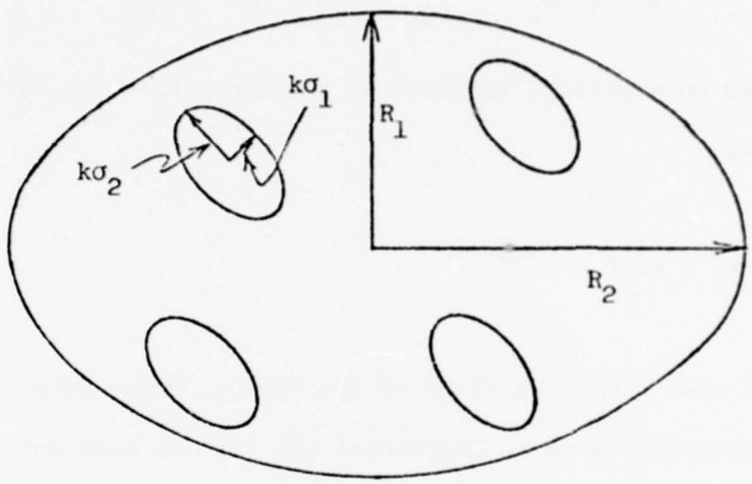


Figure B-1

The Volumes V (Large Ellipse) and δV

$$\frac{x_1^2}{\sigma_1^2} + \frac{x_2^2}{\sigma_2^2} + \dots + \frac{x_\Lambda^2}{\sigma_\Lambda^2} = k^2, \tag{3}$$

where σ_i^2 is the ith eigenvalue of σ and x_i is the ith coordinate.
Then

$$1 - E_I = \prod_{i=1-R}^{\Lambda} \int_{\sigma_i}^{R\sigma_i} \frac{dx_i}{(2\pi\ \sigma_i^2)^{1/2}} \quad e^{-\frac{x_i^2}{2\pi\sigma_i^2}} \quad . \tag{4}$$

Equation 4 can be expressed in terms of the error function by straightforward manipulations,

$$1 - E_I = (\mathrm{erf}\ k/\sqrt{2})^{\Lambda} \ . \tag{5}$$

We now discuss the computation of the Type II error rate. This is an error which occurs when an individual who has not been enrolled in the identification system is mistakenly classified as one of the N people enrolled in the system. In general, this error rate, E_{II}, will depend on whether a candidate for identification is requested to give his name or code number before the identification process is initiated. We refer to this as a "log on" procedure. If a log on is required, then an intruder would have to choose one particular person in the system to imitate. Assuming a "casual intruder" (i.e., randomly chosen) the chances that his attribute vector will match that of the enrolled person is approximately $\delta V/V$. If, on the other hand, no name or number is required of the candidate, then the system itself must test him against all N individuals enrolled in the system. The chances that the intruder will

match any one of these N individuals is thus greatly enhanced and is approximately $N\,\delta V/V$. Both of these expressions assume that the volume of overlap between individuals enrolled in the system may be ignored and that δV is small with respect to V so that edge effects are negligible. From the above arguments we have

$$E_{II} = \frac{N\,\delta V}{V} \qquad \text{(no system log on)} \qquad (6)$$

$$E_{II} = \frac{\delta V}{V} \qquad \text{(log on required)} \qquad (7)$$

Applying Equation 2 and an analogous expression for δV, Equation 7 may be rewritten

$$E_{II} = \frac{k^{\Lambda} \prod_{i=1}^{\Lambda} \sigma_i}{\prod_{i=1}^{\Lambda} R_i} \qquad (8)$$

Finally, we define N*, the characteristic number of individuals who can be drawn at random from P and placed on the acceptance list without overlapping decision surfaces. The number N* is an important parameter for the fingerprint problem because the goal is to define a physical attribute such that all N people enrolled in the system look different from one another. That is, we have an N-class problem. For the entry access problem, however, one has essentially only a 2-class problem: the candidate is either on the list or he is not. That is, it does not matter if two individuals on the Admit list are occasionally confused.

The first name on the acceptance list is drawn with no danger of overlap and $\overline{v}_1$ can lie anywhere within V. However, the second individual must be drawn so that $\overline{v}_2$ is at least 2k from $\overline{v}_1$. Similarly, $\overline{v}_3$ must lie at least 2k from $\overline{v}_1$ and from $\overline{v}_2$. Let p(N) be the probability that no overlap occurs with N individuals on the acceptance list. Define N^* by

$$p(N^*) = .5. \tag{9}$$

Notice the similarity of the above problem to the "birthday problem" of elementary statistics. The birthday problem asks for the probability q_B that there will be no common birthdays among a group of M persons. Assume there are exactly 365 days in the year (no leap years). There are then 365^M ways to arrange the birthdays. There are 365 . 364 . ... (365-M+1) ways to arrange the birthdays with no overlap. That is, the first individual can have any birthday out of 365, the second, any out of 364, and so forth. Thus,

$$q_B = 365^{-M} \frac{365!}{(365-M)!} . \tag{10}$$

Surprisingly enough, the probability q reaches .5 for only 23 people.

Consider the N hyperellipsoids of volume δV which according to our four assumptions are distributed with random uniform distribution F throughout volume V. We want to compute the probability of one or more

overlaps. Fix attention on the first ellipsoid. There are then N-1 ellipsoids which are also distributed in uniform random fashion through V. The density of the remaining ellipsoids is (N-1)/V. To create an overlap of any of these N-1 ellipsoids with the first ellipse requires that the center of the overlapping ellipse lie within Mahalanobis distance 2k of the center of the first ellipse. Because the location of each of the N ellipsoids is an independent event, we may use Poisson statistics to compute the probability of no such overlap, "q_1". The density of spheres of concern, N-1/V and the volume of interest, $2^{\Lambda}\ \delta V$, yield

$$q_1 = \exp(-(N-1)2^{\Lambda}\ \delta V/V) \tag{11}$$

Now fix attention on the second ellipsoid. The density of remaining ellipsoids is (N-2)/V. Thus, the probability that none of the remaining N-2 ellipsoids overlap with the second, q_2 is

$$q_2 = \exp(-(N-2)2^{\Lambda}\ \delta V/V). \tag{12}$$

Similar expressions hold for all the remaining ellipsoids, yielding q_3, q_4, ... , and q_{N-1}. The joint probability of no overlap, q, is given by their product,

$$q = q_1 q_2 q_3 \cdots q_{N-1}, \tag{13}$$

or

$$q = \exp(-N(N-1)\delta V 2^{\Lambda-1}/V) \tag{14}$$

Finally, we obtain as definition of N^*

$$.5 = \exp(-N^*(N^*-1)2^{\Lambda-1}\delta V/V) \tag{15}$$

B.3. SUMMARY OF RESULTS

Assembling our results we have from Equation 5 for the Type I error rate

$$E_I = 1 - \mathrm{erf}(k/\sqrt{2})^{\Lambda}\ . \tag{16}$$

For the Type II error rate, we have

$$E_{II} = \frac{R^{\Lambda} \prod_{i=1}^{\Lambda} \sigma_i}{\prod_{i=1}^{\Lambda} R_i} \tag{17}$$

Finally, for the characterstic value of N,

$$.5 = \exp(-N^*(N^*-1)2^{\Lambda-1}\ \delta V/V) \tag{18}$$

B.4. APPLICATION

The application we shall consider is the use of the electrocardiogram (ECG) to identify individuals. Two independent pieces of evidence show

that there are about 50 independent measurements which may be extracted from an ECG. Dun, et. al, (cited in MacFarlane and Lawrie, 1974) started with 300 measurements on each ECG, but found that only 50 measurements were necessary to separate normals from all types of abnormals. Secondly, it has been observed that 99% of the energy of an ECG lies in the first 24 harmonics of the power spectrum (Blackburn, 1969). Since two numbers, a sine and cosine coefficient are necessary for each harmonic, we again arrive at a number of order 50 for the intrinsic dimensionality of the measurement space of an ECG. Thus we set $\Lambda = 50$.

The value of k, which defines the decision surface, is determined through Equation 16 once the Type I error rate is chosen. Suppose we pick an error rate of 0.01. Then k is roughly 3.73.

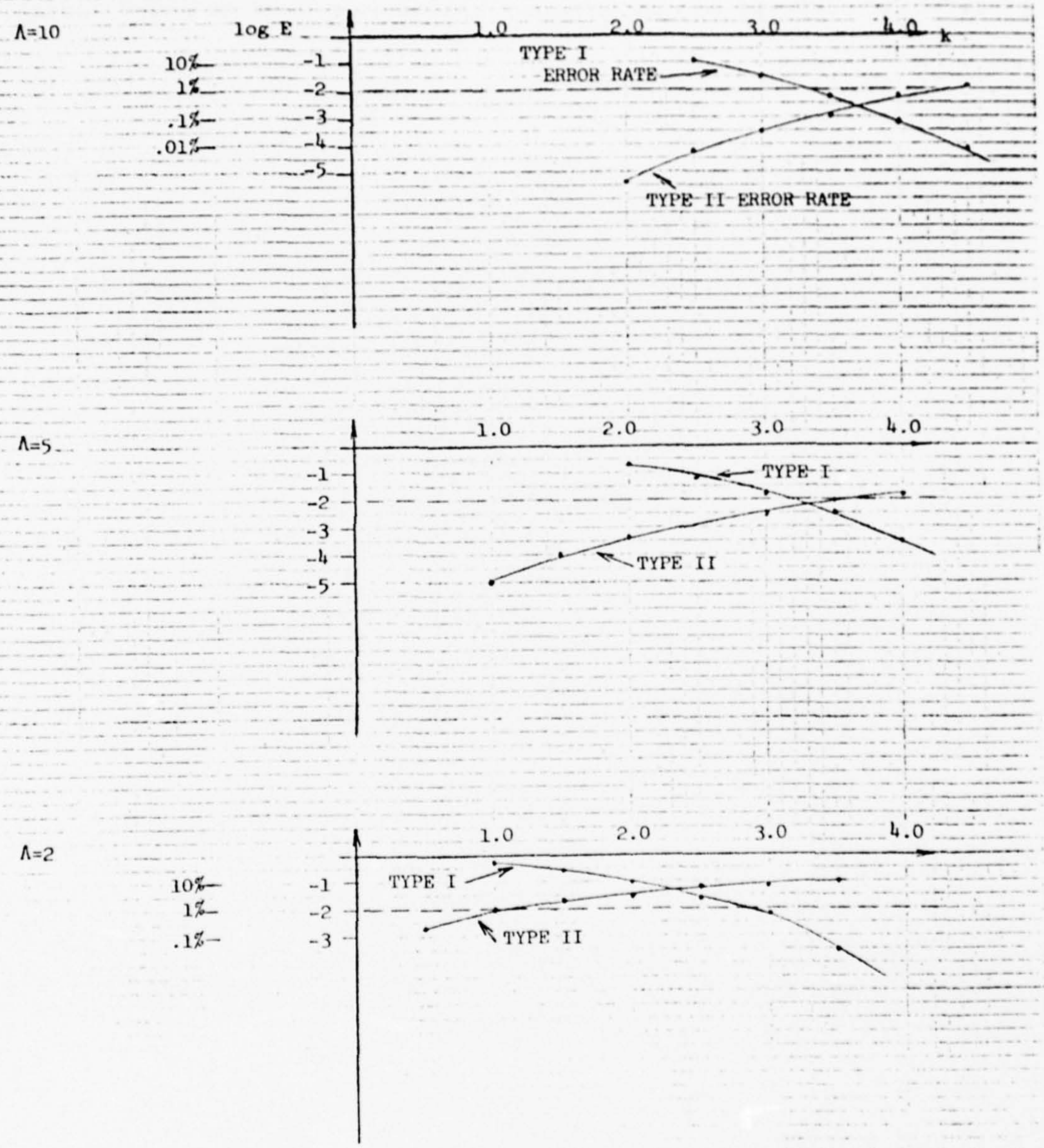
We would now like to evaluate the Type II error rate. Simonson, et. al. (1949) have gathered statistics on individual variability and range of ECG measures among the normal population. In order to apply Equation 17 directly, we would need to know the variances σ_i^2 of fifty independent measurements. We also need the ranges R_i, which may be given for fifty different measurements. From the work of Simonson, et. al.

(1949) we have only 35 measurements reported. Furthermore, we have no guarantee of the independence of these measurements. Nevertheless, we proceed as if the measurements were independent and take the standard deviation of the intraindividual variation as σ_i. Simonson, et al report the standard deviation of the interindividual variation. To obtain an estimate of R_i we set R_i equal to $\sqrt{3}$ of the reported interindividual standard deviation since a uniform distribution of extent $\pm\sqrt{3}s$ has a standard deviation of s. The data taken from Simonson et al is assembled in Table B-1. From Equation 17 it is clear that $k\sigma_i/R_i$ must be smaller than one if the ith measurement is to be of much use in distinguishing individuals. Fourteen of the entries in Table 1 have $\sigma_i/R_i > 3.73$. Let us suppose that these features are eliminated so that we are reduced to 21 features. Now a Type I error rate of .01 implies R = 3.51. Evaluating Equation 17 from Table B-1 yields

$$E_{II} \approx 4 \times 10^{-6}$$

To evaluate N* for ECG measurements we turn to Equation 18. It is immediately apparent that any measurement for which $2k\,\sigma_i > R_i$ will not contribute to a favorable value of N*. Returning to Table B-1 we find even fewer measurements which satisfy this restriction. Let us suppose that only the ten best measurements are chosen, namely 3, 4, 5, 10, 14, 22, 23, 24, 25, and 33. In Figure B-2 we present a plot of E_I and E_{II} as a function of k for these ten measurements. For purposes

of comparison, graphs of E_I and E_{II} are also given in Figure B-2 for Λ =5 and 2. The crossover point of E_I and E_{II} for Λ=10 occurs near k=3.5. Assuming this value of k, we obtain from Equation 18 a value of N* near unity. Thus, ECG measurements appear to be unsuitable for fingerprint purposes but potentially useful in regard to entry access.



B-14

Figure B-2

Type I and II Errors For Various Choices of Λ

Table B-1

Limb Leads [amplitudes in units of .1mV]

	Feature name	$\sqrt{3}$ · interindividual standard deviation	intraindividual standard deviation
1	P_2	.421	.141
2	R_1	3.43	.548
3	R_2	7.41	.64
4	R_3	9.11	.83
5	Σ_{QRS}	15.12	1.49
6	$RS\text{-}T_1$	.294	.152
7	$RS\text{-}T_2$	.346	.182
8	$RS\text{-}T_3$	.416	.155
9	T_1	1.58	.387
10	T_2	3.10	.439
11	T_3	1.97	.443
12	Σ_T	5.66	.814

Axis [degrees]

13	QRS	28.6	6.56
14	T	69.3	9.99

Intervals [.01 seconds]

15	R-R	22.9	8.59
16	Δ MAX-MIN RR	11.95	5.4
17	P-R	4.04	.854
18	QRS	2.27	.400
19	K_{QT}	.036	.015
20	K_{SVST}	.029	.011

Chest leads [.1mV]

21	$R\text{-}CF_1$	.727	.27
22	$R\text{-}CF_2$	4.22	.58
23	$R\text{-}CF_4$	12.52	1.60
24	$S\text{-}CF_1$	10.17	1.31
25	$S\text{-}CF_2$	15.84	2.27
26	$S\text{-}CF_4$	6.39	1.30
27	$RS\text{-}T\text{-}CF_1$	.61	.19
28	$RS\text{-}T\text{-}CF_2$	1.04	.44
29	$RS\text{-}T\text{-}CF_4$	.97	.35
30	$T\text{-}CF_1$	2.44	.57
31	$T\text{-}CF_2$	3.36	.84
32	$T\text{-}CF_4$	3.48	.86
33	$R/S\text{-}CF_1$	.16	.02
34	$R/S\text{-}CF_2$	.31	.05
35	$R/S\text{-}CF_4$	9.92	3.05

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1. Blackburn, Henry, Measurement In Exercise Electrocardiography, Charles C. Thomas Publications, 1969.

2. MacFarlane, Peter W. and T.D.V. Lawrie, An Introduction to Automated Electrocardiogram Interpretation, Butterworth and Company, London, 1974.

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APPENDIX C

PERSONAL ATTRIBUTE STUDY

ACCEPTABILITY ANALYSIS

One vital factor in the selection of a personal attribute for identification purposes is the acceptability with which a particular measurement technique is received. This study is an attempt to evaluate users' impressions as to the acceptability level of a set of these measurement techniques.

Subjects were given a booklet containing an instruction sheet and a set of 16 hypothetical identification situations. They were to simply read the description of a particular situation and rate it in terms of acceptability on a scale from 1 to 10. Two examples (personal recognition by a guard and the analysis of blood and urine samples) were provided to provide a standard context in which to rate the remaining situations. (A copy of the booklet is attached.)

Subjects were all employees of PAR and consisted of 6 females (secretaries and clerical personnel), 5 males from the Personal Attribute Group (scientists and engineers), and 15 additional males selected at random (programmers and other technical personnel).

It was determined *a priori* that the three groups of subjects would be analyzed separately. (The statistical evaluation of inter-individual variability was not attempted due to the lack of available analytic routines.)

Means and standard deviations were collected across subjects (within groups) for each situation, and are shown in Table C-1. Although two situations were included as anchors (Badge and X-Ray), the numbers in the table should be interpreted as relative to one another.

The situations are ranked in the table in order of their acceptability as rated by the 15 males. The standard deviations reflect the consistency of ratings within a group. Notice that the measurement of nail grooves for the females has a mean rating of 5.50, and a standard deviation of 3.73, implying that there was substantial disagreement in terms of the acceptability of this measurement. Also, the mean standard deviation for the personal attribute group was (statistically) lower than for the other groups. In addition, their mean ratings were lower. The implication is that this group was more united in their ratings, and furthermore tended to rate the measurements as more acceptable than the other two groups of subjects.

Some general trends can be inferred from the data. Across groups, the subjects tended to prefer procedures that were very fast and inherently passive. In this regard, hair color, height/weight, and flashing a badge were all very acceptable (but the females were not quite so happy with the height/weight measurement). Subjects were happy with the photoplethysmograph, if they did not need to attach a clip to their ear. The females did not like the fingernail measurement (perhaps because they could not use nail polish).

Slightly less acceptable are procedures which are perceived as requiring more time. BCG, hand tremors, and typing a name fall in this group. Despite their slightly lower acceptability ratings, they are certainly viable candidates. Stronger reactions can be seen against measurements requiring

Table C-1

Procedure	PAR Males (N=15)		Pers.Att.Group (N=5)		PAR Females (N=6)	
	Mean	SD	Mean	SD	Mean	SD
Hair Color	1.47	0.52	1.80	0.84	2.20	2.68
Height/Weight	1.60	0.74	1.40	0.55	3.60	2.51
Badge	1.60	0.91	1.80	0.45	1.17	0.41
Photopleth. (Finger)	1.93	0.96	2.20	0.84	3.00	2.61
Nail Grooves	2.40	1.35	2.00	0.71	5.50	3.73
BCG	2.40	1.96	2.60	1.14	3.50	2.95
Hand Tremor	2.67	1.50	2.80	1.64	2.50	1.97
Type Name	2.87	1.73	2.40	1.52	2.50	2.35
EKG (Finger)	3.13	1.13	3.60	2.97	3.83	1.94
Ear Ridges	4.13	2.10	3.40	1.52	4.00	2.97
VEP (W/Ear Clip)	5.13	2.10	3.80	1.64	5.50	2.07
Photopleth. (Finger & Ear)	5.33	2.09	4.20	1.79	5.67	1.03
Question/Answer	5.40	2.23	3.60	1.95	7.33	1.75
EKG (Finger & Ear)	5.47	2.13	4.00	2.00	5.67	2.07
Bite Pattern	6.33	2.55	6.20	2.86	6.33	1.21
X-Ray	7.67	3.11	10.00	0.00	7.17	3.37
Means	3.73	1.69	3.49	1.40	4.34	1.69

electrodes, or the use of the face, ear, etc. (e.g., bite pattern, EKG, ear ridges). Perhaps surprisingly, the question/answer routine was quite unacceptable. Time was an obvious factor here.

Overall, the eight top procedures in the table appear to be reasonably acceptable to these subjects. (A possible exception is the nail groove analysis for the females.) A word of caution is in order, though. Every subject in this study has a security clearance, all have been briefed at some time as to the importance of maintaining national security, and all have worked on military related projects. Thus it is quite possible that these people are predisposed to accepting an identification procedure that other people would find entirely unacceptable. Moreover, all the subjects were white collar, skilled, highly skilled, or professional people. How other classes of people would react to the various procedures is an open question. For example, how would a janitor, who happens to be functionally illiterate, react to a procedure where he was required to type his name? How would someone with cerebral palsy to the hand tremor measurement? Or someone confined to a wheelchair to the height/weight measurement? It appears that for any of these methods to be acceptable, the target user population must be explicitly acknowledged and analyzed in detail.

NAME ____________________________________

INSTRUCTIONS FOR IDENTIFICATION STUDY

In dealing with certain aspects of military and governmental operations, security of areas is an important consideration. National security necessarily requires that access to certain locations (for example, a vault containing secret documents or a laboratory for weapons research) be limited to specific individuals. Now in order for these people to gain admission to a secured location, there must be some way of positively identifying the people. There are two aspects to the problem. A procedure must recognize those people entitled to enter with a minimum of delay and inconvenience. Likewise, the procedure must correctly recognize people not entitled to enter the area.

The purpose of this study is to evaluate several possible types of identification procedures in terms of user acceptability. Consider that you are required to enter a secured area as part of your job. A certain amount of inconvenience will necessarily be encountered in the process of gaining access to the area. For example, at one extreme you might only have to be seen by a guard who will recognize you (and say "Good morning"). At the other extreme, you might be required to submit to a blood and urine analysis for positive identification. Obviously, these two examples are quite different in terms of their level of acceptability by the person being identified. In fact, some procedures might be so unacceptable that a person might resign from his/her position rather than submit to the procedure.

Below is a set of identification procedures. You are to read a procedure and then rate it on a scale from 1 to 10 in terms of how acceptable it is to you.

If a procedure is totally acceptable, it should receive a rating of 1. If it is totally unacceptable, it should receive a rating of 10. Intermediate degrees of acceptability should receive corresponding ratings. In the above examples, the guard recognition procedure might receive a rating of 1, implying that it is a totally acceptable identification technique. The blood and urine analysis might receive a rating of 10, implying that it is a totally unacceptable procedure. Remember that acceptability is an overall term covering such aspects as inconvenience, physical discomfort or injury, psychological discomfort or injury, embarassment, etc. You should interpret acceptability as reflecting these factors and any other factors which you feel are important. Please take time to completely consider each procedure.

NOTE: Each procedure will describe what is being measured, observed, etc., and what the situation will look like from the point of view of the person being measured. In each case, the measurements obtained are compared against measurements previously obtained from you in an intiialization procedure, and if these measurements correspond to the predetermined values (for you), you are allowed to enter. The time required for any procedure is typically short: often only a few seconds and always less than 30 seconds.

Example 1.

A guard looks at you. His recognition of you will allow you to enter.

Rating_____

Example 2.

A medically trained attendant inserts a needle in your arm to obtain a blood sample. You are then asked to go into a room and urinate into a paper cup. You hand the cup to the attendant who then puts both samples into a machine. The machine measures various components of the two samples in the process of positively identifying you. (Note that this procedure, as well as most of the other procedures discussed here, will take into consideration the day-to-day variations in the measurements.)

Rating_____

Process 1.

You clip an electrical contact on each ear. (The clips are like weak spring-type clothespins, and no electricity will be flowing through them.) You then place two fingers on surfaces containing additional electrical contacts. The contacts in the surfaces and in the ear clips are used to pick up your individual heart beat (your EKG).

Rating_____

Process 2.

A flexible, sterilized mouthpiece (similar to those used by athletes) is sitting in front of you. You pick it up, place it in your mouth, and bite down. Sensors in the mouthpiece then measure your individual bite pattern.

Rating_____

Process 3.

You walk between two vertical surfaces and stand still for a short time. An X-ray of your body is taken and used to identify you.

Rating_____

Process 4.

You place two fingers on surfaces containing electrical contacts. You then look through a device which resembles a pair of binoculars. The contacts in the surfaces and in the binocular device are used to pick up your individual heart beat (your EKG).

Rating_____

Process 5.

You walk over to a specific area on the floor, stand still, and hold your breath for 3-5 seconds. The vibrations of your body are picked up by sensors in the floor and are used in your identification.

Rating_____

Process 6.

This procedure recognizes you by measuring the light passing through your fingers (similar to the red light which is seen passing through your hand when a flashlight is shined on your hand in a dark room). You place the index finger from each hand on two surfaces. Each surface contains a small light source and a sensor. The light reflected off your fingers is then measured.

Rating_____

Process 7.

You sit in front of a computer terminal consisting of a typewriter keyboard and a TV. You are asked a short set of questions about your private life such as: What is your dog's name, or What is your mother's maiden name. Each time a different set of questions is asked. In addition, if you feel that such questions are an invasion of your privacy, you may answer fictitiously. The only requirement is that your answers be consistent each time the same question is encountered.

Rating_____

Process 8.

You place the index finger of each hand in two grooves on a surface such that your palms are facing upward. A TV camera under the surface takes a picture of the fingernail of each index finger. The very small grooves in your fingernails will be measured and analyzed in the same way that fingerprints are measured. (There can be no polish on the nails of the index fingers.)

Rating_____

Process 9.

You sit in front of a typewriter and type your name and a code word. The rhythm pattern of your typing is the measurement. It does not matter whether or not you are a touch typist.

Rating_____

Process 10.

A sensor in the ceiling measures the color of your hair. Variations due to dampness, sun bleaching, etc. are taken into consideration in comparing your hair color to previous measurements.

Rating_____

Process 11.

You sit down and look through a device which resembles a pair of binoculars. This places your head in the proper position. When you are positioned, a TV camera will take a picture of your ear. The ridges and valleys of your ear lobe will be measured as part of this procedure. (If your hair covers your ear, you will be required to hold it back so that your ear is completely exposed.)

Rating_____

Process 12.

You pick up a pencil-like flashlight and hold it in your hand. You then point the light at a target for a few seconds. The slight movements of your hand will be measured by photosensors in the target.

Rating_____

Process 13.

This procedure recognizes you by measuring the light passing through your fingers (similar to the red light which is seen passing through your hand when a flashlight is shined on your hand in a dark room). You clip two contacts to your ears. (The clips are like a weak spring-type clothespin.) You then place the index finger from each hand on two surfaces. Each ear clip and each surface contains a small light source and a sensor. The light reflected off your earlobes and fingers is then measured by the sensors.

Rating_____

Process 14.

Your height and weight are automatically measured. The floor on which you are standing contains a scale, and the walls contain photocells for measuring your height.

Rating_____

Process 15.

This procedure involves measuring the electrical activity in your brain after you see a light flash. You first clip an electrical contact on your ear. (The clip is like a weak spring-type clothespin, and no electricity will be flowing through it.) You then look through a device which resembles a pair of binoculars. You will see a short (but <u>not</u> intense) flash of light. The electrical contact will pick up the activity in your brain as a result of seeing the flash of light. (Note that no pain is involved.)

Rating_____

Process 16.

You are wearing a badge with your name and picture on it. A guard sees that your face matches the face in the badge picture and that your name is on his list of people.

Rating_____

Any comments you have concerning the acceptability of any of the above procedures will be most welcome. Simply indicate the procedure number(s) and your comments on this sheet.

APPENDIX D

INITIAL STUDY OF CANDIDATE PERSONAL ATTRIBUTES

D.1. FLEXION CREASES

"It has long been said that it is impossible to find two leaves exactly alike: Nature never repeats. Choose no matter what part of the human body; examine it and compare it with care in different subjects, and the points of dissimilarity will seem to you the more numerous the more minute your examination."[1]

This quote from Bertillion, a well-known criminologist and student of identification techniques whose work preceded the development of modern fingerprint methods, justifies the search for additional attributes that might be used for personnel verification. This note suggests the investigation of the flexion creases of the hand as one such attribute.

"As there are no two natures alike, so there are no two hands alike." Cheiro [2]

Cheiro's statement regarding the palmist's grist - the flexion creases, or lines of the palm, that have common names such as "life line," - serves to alert us to the possibilities of their use in personnel verification. His attention to detail has provided a rich description of the variability of such lines.

What is a flexion crease? Dorand's Medical Dictionary [3] gives the following definition:

"Any of the normal grooves across the palm which accommodate flexion (the act of bending or condition of being bent) of the hand by separating folds of tissue."

In order to describe the geometric patterns of flexion creases (palmar creases, if they occur on the palm), a few definitions are introduced now that are used to describe the general anatomy of the hand. Figure D-1 shows the bones of the hand in outline form. Note the order of the numbering of the thumb (I) and fingers (II-V). The phalanges (finger bones) are labeled "proximal, middle, and distal" in order of increasing distance from the metacarpus (the part of the hand between the wrist and the fingers). The bones of the hand are comprised of the fourteen ossa digitorum manus (five proximal phalanges, four middle phalanges, and the five distal phalanges) of the thumb and fingers, the five ossa metacarpalia of the metacarpus and the eight ossa carpi of the carpus (wrist).

The flexion of the fleshy part of the hand is constrained to occur at the joints between the bones, of course. The resulting flexion creases that manifest themselves in the skin are generally related to such motion and can be found, to first order, in predictable locations. Thus, there are usually one or two transverse creases associated with the joint between the middle and distal phalanges, two or three creases associated with the joint between the proximal and middle phalanges and two or three creases associated with the joint between the metacarpal and proximal phalange for each finger. In addition, there are several palmar creases that are found in common locations.

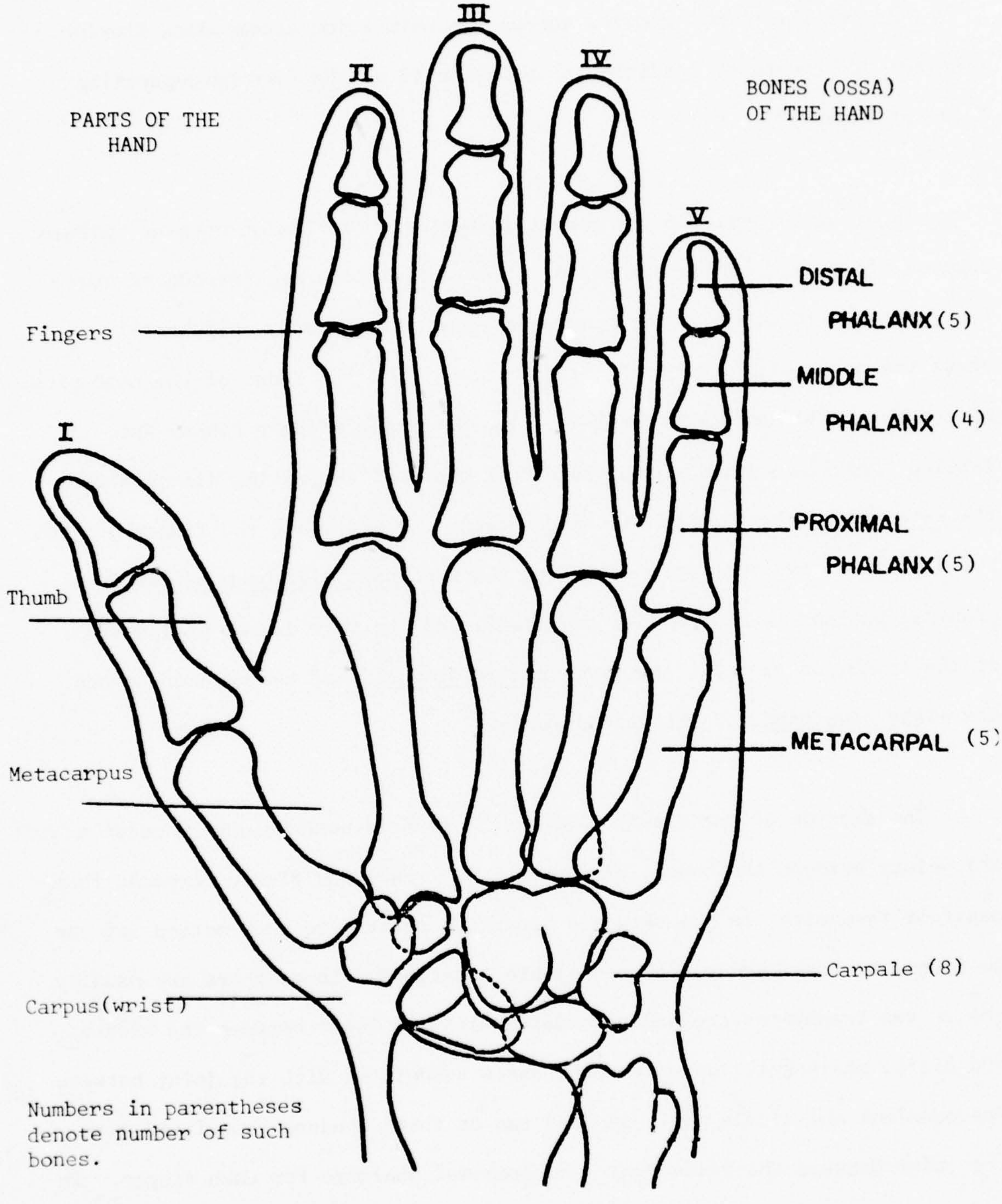

Figure D-1 General Anatomy of the Hand

Figure D-2 is a schematic representation of the surface of the palmar side of the hand showing the usual location of the flexion creases and a number of other flexure lines and features of the skin's surface. Some additional terminology is introduced at this point for future use. With respect to the major flexion creases of the palm, "proximal" and "distal" refer to distance from the thumb across the width of the palm. "Transverse" and "longitudinal" refer to the orientation of a line on the palm with respect to the hand, with transverse being across the hand (from the thumb to the palm margin) and longitudinal along the length of the hand (parallel to the fingers).

There are three major flexion creases of the palm:

1. Radial Longitudinal Crease
2. Proximal Transverse Crease
3. Distal Transverse Crease

These are shown as thick lines in Figure D-2. Either the Radial Longitudinal Crease (the palmist's Line of Life), the Proximal Transverse Crease (Line of Head) extend separately, or they join together (as shown) before reaching to the thumb side of the palm, or proximal margin. The Distal Transverse Crease (Line of Heart) usually extends to the distal margin of the palm. Table D-1 summarizes the locations of these (and other) flexion creases commonly found on the palm. Also listed in Table D-1 is the joint flexure that is most strongly associated with each crease. For example,

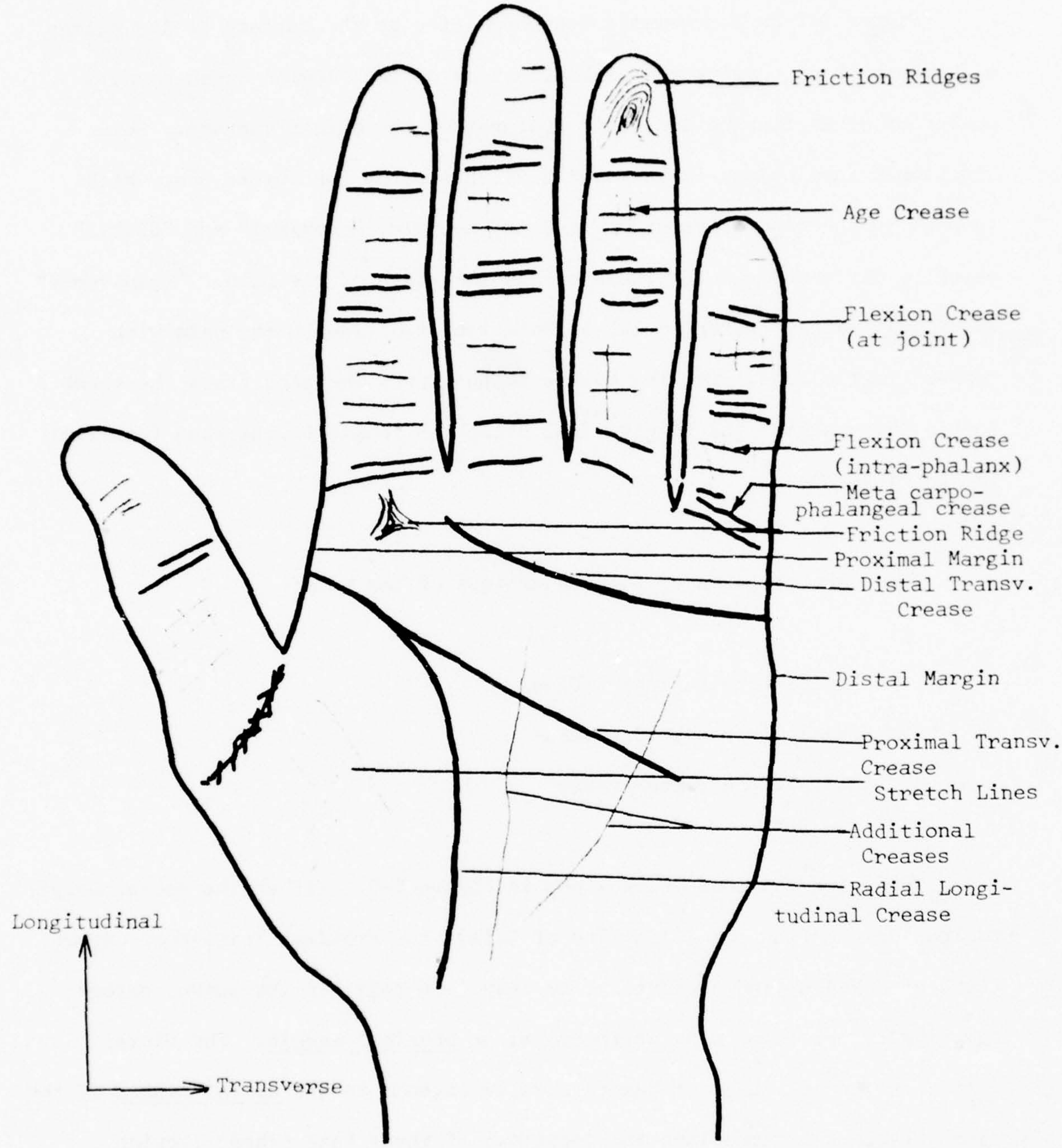

Figure D-2a Surface Attributes of the Skin of the Palmar Side of the Hand

LETTER	CREASE NAME (Scientific/Palmistry)	ASSOCIATED FLEXURE JOINTS
a	Secondary Radial Longitudinal "Line of Mars"	First Meta-Carpale/ Carpale
b	Primary Radial Longitudinal "Line of Life" (if on left hand)	First Meta-Carpale/ Carpale
c	Primary Proximal Transverse "Line of Head"	Proximal Phalanges/ Meta-Carpales
d	Secondary Proximal Transverse "Girdle of Venus"	Proximal Phalanges/ Meta-Carpales
e	Primary Medial Longitudinal "Line of Fate"	First and Fifth Meta-Carpale/ Carpale
f	Secondary Medial Longitudinal "Line of Sun"	First and Fifth Meta-Carpale/ Carpale
g	Tertiary Medial Longitudinal "Line of Health"	First and Fifth Meta-Carpale/ Carpale
h	Secondary Distal Transverse "Line of Marriage"	Fifth Proximal Phalange/ Fifth Meta-Carpale
i	Primary Distal Transverse "Line of Heart"	Third, Fourth, & Fifth Proximal Phalanges/Meta-Carpale
j	Carpale Transverse "Bracelet"	Carpales (wrist)/Ulnar (arm)

Table D-1 Crease Names and Associated Joints (See Figure D-2b for Locations)

flexure at the metacarpal/proximal phalange joints of fingers III, IV and V would be associated with the Distal Transverse Crease.

Figure D-2 also shows the existence of additional attributes of the skin surface on the palmar side of the hand. The most commonly used method of positive identification today is fingerprinting which makes use of the unique combination of patterns of friction ridges at the fingertips. The whorls, loops, arches and minutia form a permanent, imbedded dermatoglyphic signature that doesn't (organically) change from birth to death in its topology [4, 5, 6]. As is well known, fingertip friction ridges have been collected manually by ink transfer imprints by such agencies as the Federal Bureau of Investigation (FBI) and almost every local law enforcement department.

Automatic scanning, retrieval and matching systems are being developed by the FBI and such companies as Sperry Rand Corporation, Rockwell International and Calspan Corporation. A Calspan unit was to have been tested for the Base and Installation Security System at Ellsworth Air Force Base under the CAVEAT program. The following quotes from the FBI Law Enforcement Bulletin, December 1961 (revised March 1969) underscores their belief in the utility of this attribute.

"Of all the technical procedures employed in criminal investigations, none exceeds the potential value of the latent fingerprint examination. By this means alone, many crimes have been solved and the perpetrators identified beyond all doubt.

The positive nature of fingerprint identification is based on the following two facts which have been established through observation for many, many years:

1. Every finger of every person bears a ridge arrangement which is unique.

2. Barring cases of accidental or surgical removal, this pattern is permanent for the life of the individual and endures until decomposition of the skin after death."

Because of existing programs utilizing fingerprints as the personal attribute, the Statement of Work for this effort specifically excluded it from our investigation. The next sentence in the FBI bulletin says, however:

"These statements are true also of the ridges on the palms of the hands and on the toes and soles of the feet. Identifications of these areas have the same technical and legal validity as fingerprint identifications."

Indeed, considerable analysis of friction ridge patterns on palms and soles have been made in addition to those of the fintertips [6, 7, 8]. Palm prints have been used in the study of schizophrenia [9, 10, 11] and other genetic disorders [12]. Palmar flexion creases have been suggested as indicators in Down's syndrome and leukemia as well [13]. Because schizophrenia [14] and Down's syndrome [3] have suggested as having genetic

origins, and dermatological features such as friction ridges and flexion creases also are considered to be genetically determined [4], it is natural to search for a correlation between these disorders and the patterns of ridges and creases.

Congenitally formed attributes are of particular interest to this project because they exist from birth, tend not to change drastically or rapidly with age, and may be unique to the individual.

The hand surface is rich in such characteristics. Montagna [4] states:

> "... ridges in the palms and soles, inherent flexion lines and the countless fine lines over the entire surface of the skin are all congenitally formed."

Congenitally formed lines are not the only lines, however, as it is commonly known that wrinkles and furrows develop with age and use. However, this is believed to be a slow process which could be tracked, if necessary, with regular updating of the reference data stored for each individual. It might also indicate to some extent the environmental conditions that each individual was exposed to during his or her prior years that influenced the formation of such wrinkles and which might further aid the personnel verification process. Flexion creases, however, are permanent attributes as they indicate the locus of points at which the skin has a firmer anchoring to the subcutaneous tissue. They also tend to show the arrangement of the collagen-

ous fibers in the dermis. Thus, they form a pattern of lines on the hand that, particularly when stretched, can possibly be differentiated due to a color difference caused by the presence and absence (at the crease) of collagea in the lower layers of the skin. With the absence of much pigmentation on the palmar side of the hand, the epidermis (top living layer of the skin) tends to be translucent.

Visual inspection of the lines, e.g. flexion creases, of the hand reveal many types of features that characterize them. Figure D-2b shows the location of possible crease lines (a, b, ..., j). The most common of these are b (radial longitudinal), c (proximal transverse), i (distal transverse) and j (carpale transverse). Often, the radial longitudinal crease will be completely separate from the proximal transverse crease, as shown by the dashed line. It is also common for the proximal and distal transverse creases to be joined by a bridging crease, also shown in dashed lines.

In addition to the palmar and carpale locations, creases exist at the phalangal joints (designated 0, 1, ..., 5), and facilitate the folding of the skin as required by natural bending of the fingers. These creases are fairly distinct and seem always to be there. They vary in number and crease characteristics, but may prove useful, for example, in measuring phalangeal lengths.

Cheiro [2] described the shapes of hands, the characteristics of palmar creases and unusual marks on the palm. Of course, his use of these features was different, and perhaps more entertaining, but their descrip-

A. Outline

Palm width
Wrist width
Finger lengths
Finger widths

B. Digit Creases

Solid
Broken
Parallel - 2 more
Crossing
Branching

F. Stretch Lines

Dense
Longitudinal
Transverse
Both
Sparse

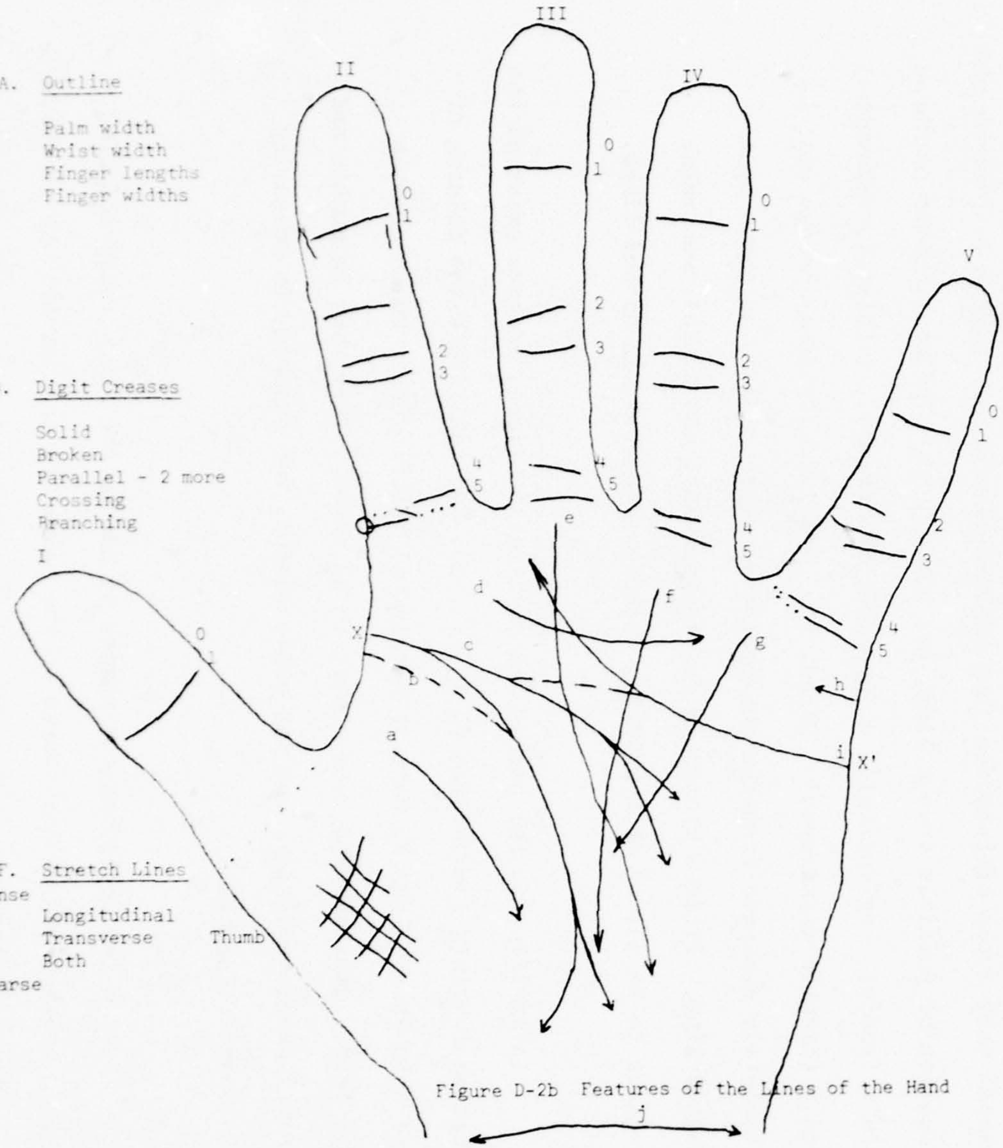

Figure D-2b Features of the Lines of the Hand

C. Wrist and Palmar

Solid line
Parallel line
Flared lines
Branching (up, down, both)
Broken lines
Wavy lines
Corded lines
Chained lines
Cross-hatched lines
Stepped lines
Spots on line
Islands on line
Squares on line
Forked ends
Tasselled ends
Capillaried ends

D. Unusual Marks

Extra creases
Scars
Geometric Figures(isolat)
Star
Island
Spot
Cross
Triangle
Square
Circle
Tripod (fork)
Arrow

tion provides a useful basis for the set of features shown in Figure D-2b.

The outline of the hand can provide several gross statistics which in conjunction with other measurements may be useful for personnel verification. Identimation Corporation sells a commercial product for this purpose based simply on finger lengths alone. There are enough fingers on one hand that are sufficiently uncorrelated in length to provide verification at slightly above the desired first level error goals of the Base and Installation Security System (BISS) [16], as tested in recent experiments [17]. If additional measurements were made, e.g. finger thickness, palm width, thumb length/curvature, wrist width, etc., a convenient and workable system may result, using only these features. Palm width, for example, could be measured from X to X' (see Figure D-2b) which are the intersections of the two major transverse creases (extended if necessary) and the proximal and distal edges of the palm, as shown in the outline. Simple shadograph technology might suffice to obtain these edges. Even if the creases were not used, a minimum width algorithm could be used to obtain a unique and consistent measure of palm width. Finger lengths are not necessarily correlated with palm width. Also finger lengths and widths may be sufficiently uncorrellated so as to provide additional uniqueness. Even finger widths at the joints compared to widths measured in the middle of each phalange may supply additional information.

The existence, location and curvature function of crease lines provide a potential wealth of information as to the identity of an individual.

Furthermore, each crease can be one of several types as shown in Figure D-2b. Such characteristics as solid, parallel, flared, etc., add further differentiation power to this approach. Even their ends can be different, e.g. forked or tasselled. Also, creases are marked with spots, islands and squares, as illustrated. Unusual features, if they exist, provide further means for verification. Such items as scars and geometric figures, e.g. stars, crosses and arrows, provide valuable information because of their low frequency of occurrence.

Stretch lines, for example, on the fleshy part of the palm over the first meta- caroale bone (connected to the thumb) and on the palmar side of the digits are different in depth, spatial frequency (two spectra, one for largely transverse and the other for largely longitudinal lines) and extent of coverage. These lines are not flexion creases, but are somewhat different from person to person.

It is evident, then, that the palm surface details and the projected shape of the hand contains a rich variety of features which, if measurable, should provide a sufficient set of attributes to meet the first level BISS specifications, if not more stringent requirements.

The least certain aspect of these attributes is their measurement. If contact could be made to a transparent material, then internal reflection imagery techniques could be used [18] to produce an image that could be scanned with optoelectronic transducers. These have been used to obtain high quality footprints showing clear ridge patterns [19]. The difficult

aspect of the automatic feature measurement, however, is the algorithms to process the electronically stored image, which is simply an array of reflected light intensities, whose function is to extract image lines, measure their characteristics and quantify them for use in verification logic. Such algorithms are not "off-the-shelf" and have to be developed for each application.

Several application routines already existing, for example, on the DICIFER system at Rome Air Development Center [20], such as spatial differentiation and line following, may be useful for this application. However, as is customary for nearly all unique pattern recognition problems, the set of discriminating features are also unique. Thus the creation of successful recognition/verification logic is an experimental process involving the iterative application of new data and the improvement of new feature extraction algorithms [21].

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D.2. HAIR

Hair color, like height and weight, is a classical personal attribute for identification and would be a standard item in any description of a person. But, like height and weight, it is obvious that hair color can only be a coarse discriminator of individuals. We might hope to find ten or twenty different categories of hair color once allowances are made for the day-to-day variations which will be introduced by such factors as the frequency of washing, season of the year (sun bleaching), or hair dyeing. Anthropologists use about 30 hair samples for field categorization [1].

The color of an individual's hair could be easily measured by placing a simple one-cell spectrophotometer in the ceiling of the access booth. The entrance pupil of the instrument could be focused on the subject's head by computer command once the subject's name or code number was entered into the system. Or, if the height is also to be a measured attribute, the focusing could proceed without reference to the subject's known height. In any case, the f-number of the optics would be high enough that focus would not be critical. The spectrophotometer would employ perhaps eight bandpass filters on a rotating wheel to define the spectral bands of interest. After passing the filter, the light would fall on a broad-band photomultiplier tube such as one of the GaAs types. The filter wheel, which would be in continuous rotation, could employ a shaft encoder to register the filters.

If skin color is also to be measured, a light pipe might serve to carry the signal from, say, the hand to the same spectrophotometer. In this case, shutters would be necessary to select the two signals, either hand or hair.

We now wish to discuss the possibility of making a closer examination of an individual's hair. Techniques do exist for examining the elemental composition of a single strand of hair. The hair can be distinguished as animal or human [2], and, if human, whether of Caucasian, Mongolian, or Negro origin. However, "hairs do not possess sufficient individual characteristics to be identified as originating from a particular person to the exclusion of all others" [1]. In addition, we have not been able to identify any technological means for the single hair analysis which would permit an identification system based on it to be cost competitive with other techniques.

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D.3. VENOUS PATTERNS

D.3.1. Introduction

The lineal pattern formed by the superficial veins of the body may provide a unique characteristic by which a person may be identified. Only the superficial venous pattern of the back of the hand will be considered in this discussion. There are three reasons for choosing the pattern provided by the back of the hand over any other venous pattern. One, the back of the hand provides one of the, if not the most, prominent venous patterns in the body. It is so prominent that it is usually plainly visible to the naked eye. Two, the hand is the most accessible part of the body, requiring no removal of clothing and is easily positioned for access for the sensor system. Three, the hand pattern is complex (rich in distinguishing features) compared to other venous patterns of the body, while being contained in a small area for easier processing.

D.3.2. Feature Extraction

D.3.2.1. General

Several different methods are available for the detection of the venous pattern. Photography of the pattern in either the visible or actinic (near infrared; 700-900 nm) band, or a thermographic record via liquid crystals or thermographic scanner are two potential means of

recording the venous pattern. After recording the pattern, some method must be developed to take the image data and extract a recognizable and individually unique set of characteristics from the lineal features of the venous pattern. Since this is a problem common to many of the purposed attributes, such as palm prints, ear patterns, bite patterns, etc., a separate analysis of it will not be done here.

D.3.2.2. Thermographic Pattern Extraction

One means of extracting the venous pattern is by detecting the temperature difference between the skin overlying the superficial vein and the surrounding skin tissue. The skin overlying a superficial vein will normally be slightly warmer than the surrounding skin, reflecting the higher temperature of the venous blood. This temperature difference will be more pronounced in the extremities where skin temperature variation is the highest.

Liquid crystals offer one means of detecting the small temperature differences associated with the venous pattern. The liquid crystals indicate different temperatures by taking on different colors. By applying liquid crystals to the skin, a color coded temperature map is produced. This could then be recorded by color photography. One drawback to this method is that contact with the hand is required, although by encapsulating the liquid crystal in a thin plastic sheet, no direct contact of the liquid crystal with the skin is needed.

Another method of producing a thermographic map of the skin is to record the thermal infrared radiation emitted by the skin. This blackbody radiation peaks for body temperature (310°K) at about 10 microns. There are many thermographic scanning systems available for this purpose. Currently available systems have high scan rates (16 frames/sec), high resolution (140 x 130 pixels over a 11 x 11 cm area), and high sensitivity (T = 0.1°C).

Such thermographic systems are inherently quantized in space so that direct interfacing with a digital computer is possible.

One problem with the thermographic technique lies in temperature variation, both the overall temperature variation of the hand and the variation of the temperature difference between "venous" skin and "normal" skin.

D.3.2.3. Photography Pattern Extraction

Normal (visible light) photography would not ordinarily be sufficient to define the vein pattern. However, photography in the actinic band (near-infrared; 700-900 nm) is an excellent method. Superficial veins tend to be very visible with this type of photography, recording darker than the rest of the body. The skin and superficial tissues reflect most of the infrared radiation falling on, and penetrating a short distance into, the body; whereas the blood in the veins absorbs much of the

infrared. This provides tone separation. This type of photography does not require a special camera, but rather only the use of the proper filters and film.

The distinctness of the venous pattern depends on the thickness of the overlaying skin, the degree of venous engorgement, the condition of the vein walls, and the nearness of the veins to the surface. Conditions which obscure the venous pattern include the following: a relatively thick layer of subcutaneous fat, the thickened walls of varicose veins, and the depth of certain large veins. The only condition which might obliterate the pattern on the back of the hand would be the large fat deposits of an obese person.

D.3.3. Attribute Evaluation

The evaluation will be broken into the six categories listed in Section 2.2.

D.3.3.1. Separability

Separability depends on two factors: the constancy of the characteristic and the individual uniqueness of the characteristic among the population. The constancy of the venous pattern will be high, as there is no bodily mechanism to cause the pattern to change. The main cause of change in the pattern would probably be due to error in the detection

system, and this should be sufficiently small. Information regarding uniqueness of the pattern is not known to the author. We have been unable to locate a data base of vein patterns for the hand, nor any statement to the effect that the vein pattern on the back of the hand is unique for an individual. However, from personal observation of the pattern on other people, each pattern has appeared distinctly unique. It has been observed in medical studies that it is difficult to specify a "normal" venous pattern. This has been especially noted in the existence of a wide variety of venous patterns from the female breast. We would rate separability at 80 $\pm$ 20 due to the lack of a data base from which to judge.

D.3.3.2. *Acceptability*

Observation of the hand via a non-contact imaging system should not be unacceptable to people for access to a secure area. We would rate acceptability at 85.

D.3.3.3. Technological Feasibility

Both thermographic scanners and actinic photography are well established "off-the-shelf" devices. The digitization and feature extraction from the imagry is riskier. We would rate technological feasibility at 60.

D.3.3.4. Cost

Operational cost or purchase cost of either a thermographic or actinic photographic system would be acceptable. Development costs for data collection via actinic photography are acceptable. For a thermographic scanner, arrangements would need to be made for access to a medical units device, in order to keep the cost for data collection reasonable. Even without a thermographic scanner, thermographic data could be collected with the use of liquid crystals. We would rate cost at 95.

D.3.3.5. Speed

The image processing which might be required could be quite time consumming, perhaps 10 to 15 seconds. Therefore, we would rate speed at 80.

D.3.3.6. Penetrability

An informed intruder with a preprepared infrared pattern could defeat the system. However, the cost of constructing a fake pattern is high, and is higher than for a similar optical system. We would rate penetrability at 80.

D.3.4. Conclusions

We would recommend serious consideration of this attribute. Most of

the ratings for this attribute are very high. Since the hand is being considered for so many attributes, it would be easy to combine this attribute with other attributes of the hand. The main concerns are two: (1) that the patterns be individually unique and, (2) that the patterns be detectable for all normal physiological conditions.

D.4. PHOTOPLETHYSMOGRAPHY

Photoplethysmography is the recording of the volume of blood present in an extremity, such as the finger or earlobe, by measuring the time-varying reflectance or transmission of light at the extremity. It is a common experience to observe that one's hand will glow with a blood-red color when illuminated by a flashlight in direct contact with the skin, providing that the room is dark enough to observe the effect. The reflective photoplethysmograph employs this phenomenon. The finger or earlobe forms a reflective bridge between a light source and a light detector. These would ordinarily be diodes in the modern instrument. As the heart beats, a pressure wave travels through the vascular system. The pressure wave produces a time-varying amount of blood in the extremity and, in consequence, the amount of light reflected to the detector is also a function of time. Recording the output of the detector gives a history of the pressure pulse. Such a record is referred to as a photoplethysmogram (PPG).

The PPG is known to vary in shape and amplitude with changes in blood pressure, and hence the shape of the waveform will not serve as a stable individual feature. It can be observed to undergo changes with emotion, drugs, and exercise, for example. We propose, however, that the time of arrival of the pulse maxima at fiducial points on the body, might bear a constant ratio relation to one another. Suppose, for example, that the electrocardiogram (ECG) signal is recorded to serve as a reference signal.

The PPG is measured at the index fingers of both hands and both earlobes. The delay between the ECG maxima and PPG maxima could then be derived through standard correlation methods. One would thus have available four time lags. These time lags will depend on the pulse wave velocity which will, in turn, depend upon heart rate. The heart rate could also be derived from the signals and a correction applied to the four time lags. This procedure would result in four numbers which would essentially be the path length from the heart to the fiducial points. Alternatively, one might form the ratios of the four numbers to obtain three independent numbers which would now be proportional to the ratios of the four lengths.

In Figure D-3 we show a typical photoplethysmogram. Judging from the sharp maximum, we might hope to achieve a time lag accuracy of 1/100 of the period of the wave train. Taking the period to be approximately 1 second for the normal heart beat and taking the velocity of propagation of the pulse wave as 7 m/sec, we see that a measurement accuracy of 7 cm might be attainable. This is comparable to the resolution cells which we have contempleted in the case of height (2 inches), and we may consequently conclude that PPG delays can provide only a coarse characterization of an individual. The accuracy estimate is our best technical opinion based on the observed harmonic content of the PPG in Figure D-3. It is possible that higher accuracies might be reliably obtained, but it is clear that an accuracy of 1/1000 of the pulse period is called for before the PPG delays we have described can serve by themselves as useful individual discriminants.

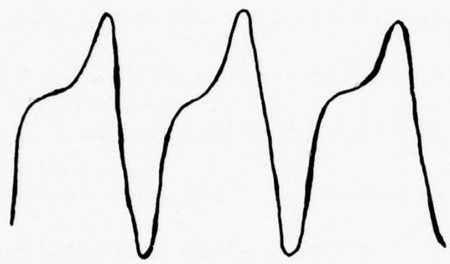

Figure D-3

D.5. RESISTIVITY OF THE HUMAN TORSO

D.5.1. Theory of Magnetically Coupled Inductance

The resistivity of a conductive body (such as a human body) can be measured by inductive magnetic coupling without making physical contact with the body. The basic principal is as follows. A transmitting coil is energized with a sinusoidal current which creates a time varying magnetic field in its vicinity. A second receiving coil is located at a fixed distance from the transmitting coil, where it picks up a signal voltage due to the oscillating magnetic field of transmitting coil. When a conductive body is brought into the vicinity of the transmitting coils, currents are induced in that body which are proportional to the conductivity of the body. These induced currents in turn produce a time varying magnetic field. This magnetic field due to the conductive body becomes a second source of signal to the receiving coil. This signal voltage is several orders of magnitude smaller than the signal from the transmitting coil, so electronic processing is used to cancel the transmitting coil signal to about one part in 10^7. One important aspect of this type of measurement is the sensitivity of the signal to the distance of the probe from the conductive body. In one experiment, a change in distance from the probe to a human body from 73.5 to 106.8 mm produced a 70% reduction in signal voltage. The signal voltage appears to drop as the seventh power of distance.

D.5.2. Technical Setup

The type of physical setup for access control using this type of attribute would involve some technical advances over present equipment design. Since it is doubtful that each individual has a unique body resistivity, one would need several probes, measuring resistivities at different points on the body, to form a pattern of body resistivities. This pattern of resistivities may then be unique to the individual. However, some means of measuring and correcting for changes in probe-to-body distances would be needed in order to match measurements taken at different times. Some means would also need to be developed to automatically correct for metal objects on a person's attire. Such objects would include metal buttons, jewelry, pens, glasses, belt buckles, change in a pocket, watches, etc. Obviously, removal of all such objects would prove unacceptable. However, the phase of the signal voltage due to metallic objects differs from that of the non-metallic body. Additionally, of more than one probe were used simultaneously, some means to prevent cross-talk between the probes would be needed.

D.5.3. Attribute Evaluation

D.5.3.1. Separability

Since the resistivity of the body depends on the basic salinity of the body tissues, changes in the salinity will change the resistivity

attribute. Changes due to the imprecision of the measurement equipment could be very significant. The uniqueness of any one, or any pattern of, resistivity measurements is simply not known. No data base of such measurements exist. Since people are all grossly the same type of saline bag of water, we would not imagine that large differences in resistivities exist. We would rate separability at 60 ± 35.

D.5.3.2. Acceptability

If technological improvements cannot solve the problems involved with metallic objects and allowance for probe to body distance variations, then the system would be unacceptable. If such problems are solved, we would rate this at 70. The fact that it is radiatively intrusive to the body, even though very small currents are involved, makes it less than 100% acceptable.

D.5.3.3. Technological Feasibility

The method of magnetically coupled resistive measurements is technically feasible. The improvements required for an acceptable system are the areas where technical feasibility is more questionable. Although, improvements to correct for metallic objects (through phase information) and for probe to body distance variations are theoretically possible, the technological implementation would prove difficult. We would rate technological feasibility at 40.

D.5.3.4. Cost

Through a conversation with Dr. Richard McFee of Syracuse University, the co-developer of the magnetically-coupled resistive method, the author concludes that no commercial units exist; also that no improvements have been made on the basic technique. Access to the unit Dr. McFee built did not seem possible. He was interested in perhaps building a simplified version of the unit. Considering the lack of access to equipment and the improvements needed to the basic technique, we would rate cost at 10.

D.5.3.5. Speed

Speed of operation would be no problem. We would rate speed at 95.

D.5.3.6. Penetrability

It would be difficult to mimic the resistivities to an accurate enough degree, so that we would rate penetrabilities at 40.

D.5.4. <u>Conclusions</u>

We would recommend against pursuing this attribute any further. The cost-technical feasibility problem along with the uncertainty of its separability make this approach unfeasible.

D.6. TREMOR RECOGNITION

Muscular tremors have been placed in three categories by Wyatt [1]: "at rest", "intention", and "static".

Intentional tremors, those which occur while the muscles are under deliberate stress, do not manifest themselves as measurable motion and so are not considered likely for attribute verification. Similarly, the member is supported in the "rest" tremor situation thus masking tremors. Tremors become easily visible and measurable in the "static" form when the member is at rest but unsupported.

Data collection initially should consist of digitized output from a photocell which the test subject attempts to illuminate with a small light source.

A number of configurations have been suggested for the actual access room to utilize this measure. Several different motion sensing methods are available.

The pattern to be matched will be a modification of the raw motion data, possibly a power spectrum or other distillation.

Preliminary evaluation:

1. Separability - unknown until data becomes available. Wyatt

shows that finger tremors are sufficiently rich and repeatable to separate some individuals. Rating 40.

2. Acceptability - should be quite high since the method is simple, quick, painless, and non-invasive. Rating 85.

3. Equipment - rates 90, should be simple to build or modify.

4. Cost - simplicity of method and equipment gives this a high rating. Rating 90.

5. Speed - sample times in Wyatt varied from about 3 sec to over 12 sec. It is not clear how long will be required for arm tremors so speed is rated 75 for a 10-second sample and additional time for analysis.

6. Penetrability - it is difficult to imagine an agent being trained to simulate involuntary tremors. The photocell could be fooled by a light controlled by a recording of the proper person's tremors. The coil moving in magnetic field sensor would be much harder to simulate yet no more difficult to use. Rating 80.

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D.7. DYNAMIC RESPONSE OF THE HEAD

It has been proposed that the response of the head to mechanical vibration be used as a means of personal identity verification. Broad-band or narrow-band excitation of the skull could be conveniently accomplished using a piezoelectric transducer driven by an electronic wave generator, for example. The dynamic response to such excitation could then be measured by means of an accelerometer coupled to a second contact point on the head (or between the teeth [1]). Spectrum analysis might be employed to identify resonant frequencies of the skull, jaws, teeth, etc., and hence establish features for differentiating between individuals.

The concept of ID verification using the dynamic response of the human body has been patented by Ott [2]. A survey of the patent and other aspects of biodynamics is contained in Section 2.23. Key body resonances are known to exist in the 4-8 Hz range [3,4]. Studies have suggested that above 15 Hz the dynamic response of the body is highly characteristic of the individual [3,4]. Heavy damping of the incident energy is also known to occur above 100 Hz.

The technology needed to implement an ID verification system based on bio-dynamics appears available. In fact, the transducer instrumentation could be assembled using "off-the-shelf" components at a cost of a few hundred dollars. A microprocessor might also be used to process each response signal and compare it with a sample obtained from a magnetically

encoded card. Accordingly, the technological feasibility of this method rates a score of 100. Perfect scores are also associated with separability and operating speed.

However, it would be fair to say that regular users of such a system might be apprehensive about repeatedly having their "heads examined". Moreover, some discomfort could be anticipated during screening in view of the necessity for resonances of the head to be excited. It is known, for instance, that at 10 Hz the face and cheeks tend to flutter if the excitation is strong enough [5]. Similarly, dental discomfort might be objectionable, particularly for wearers of loose dentures. Also, temporarily blurred vision arising from the inability of the eye to follow the motion of a retinal image in the 3-30 Hz range [3] might be a complaint, unless users were told to shut their eyes during screening.

User acceptability would probably increase if the vibrating source were not coupled directly to the head. As alternatives, mechanical energy could be introduced to the feet or seat of a standing or sitting subject. Then the accelerometer used to measure the response of the head would in effect measure the response of the entire body, and therefore be capable of detecting the energy transmitted through it. This approach would also be suitable for ID verification. But body response measurements would be highly sensitive to posture and composure [1], so that the error rates could be expected to rise accordingly.

In conclusion, the biodynamics of the head at first glance appears to offer an attractive basis for establishing a new ID verification system. However, such a system would most likely incur considerable user resistance stemming from both physiological and psychological effects, although testing at low vibration levels might prove otherwise. In any case, a patent license would be required for implementing any of the concepts described here.

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D.8. TEETH

Fifteen teeth characteristics have been observed by Dr. Oscar Amoedo in 1898 [1]. They can be classified by the following:

A. Related to individual tooth:

- o Dimension of the tooth
- o Form of the tooth
- o Color of the tooth
- o Fillings
- o Unfilled cavities
- o Diseased tooth
- o Abnormal forms of the teeth

B. Related to the teeth arrangements:

- o Absence of teeth
- o Irregularity of teeth with their positions
- o Curve of the dental arcade
- o Width of the arc
- o Height of the vault

C. Miscellaneous:

- o Color and texture of the gum

- Artificial dental crowns
- Artificial teeth

Platschick, using a set of nine measurements on the teeth, observed that although these measurements were taken from skulls of the same race, one had never been able to find three identical measurements on two subjects, rarely two, and even one only with difficulty.

The teeth features extractable from a bite pattern are limited to those related to the teeth size, shape, rotation, and displacement. The bite pattern will be changed due to the force applied, the duration of the application, the degree of the movement between tissue and teeth during the application of the force [2], the suction and tongue thrusting force [3], and the material properties of the tissue.

The statistics extracted from models of 6 upper anteriors were studied by MacFarlane, et al at Glasgow Dental Hospital and School in 1974. [4] Two hundred samples over age 16 were randomly taken at the dental hospitals in the Glasgow area. The result shows that at 95% confidence level, 60.4% of the population aged 16 and above have six normal upper anteriors, 7.4% have six upper incisor posteriorly displaced, 21.6% have the upper left lateral incisor slightly mesio-labial rotated. Considering all these phenomena statistically independent, 8 in 100,000 of the population with some natural teeth might be expected to have a similar dentition.

Technical considerations rapidly reduces the prospective usage of bite pattern as entry control. First of all, the sensoring and recording problem. Direct sensoring equipment similar to the one used to measure the suction force [3] are beyond imagination. Indirect sensoring approaches which take the image of the bite pattern with other transducers such as a TV camera seem to be the only solution at the present time. The subject's acceptability to such an approach will not be high due to risk of infection. Secondly, the reliability of the measurements may be low. As previously mentioned, the force applied to the tissue, the duration of applying the force, etc., will change the pattern obtained for identification. To remove the deviations, or to incorporate these deviations, requires further study.

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D.9. THE EAR

> The ear, thanks to the many hills and valleys which cross it, is the most important factor for identification of the human face. Actually, it is almost impossible to come across two ears which are identical in all their parts, and some of the variations in form which that organ presents appear to continue without modification from birth to death.
>
> - A. Bertillon, 1893 -

The outer ear (herein referred to simply as the ear) of a human being consists of several visually discernable parts: the helix, the antihelix, the tragus, the antitragus, the lobe, the concha, etc. (Figure D-4). Verbal description of the size, shape, color, texture, peculiarities, location of the ear and/or the parts has been used for personal identification. The variety and richness of these features indicates that entry control based on the subject's ear structure is promising <u>if</u> these verbal descriptions can be translated into mechanically measurable properties, <u>if</u> these measurements can be obtained quickly and accurately, and <u>if</u> those features remain unchanged for a reasonable time duration.

Relevant research in digital image processing and pattern recognition yields the following results on an isolated object:

- o Object size is linearly proportional to the number of picture elements within the object boundary.

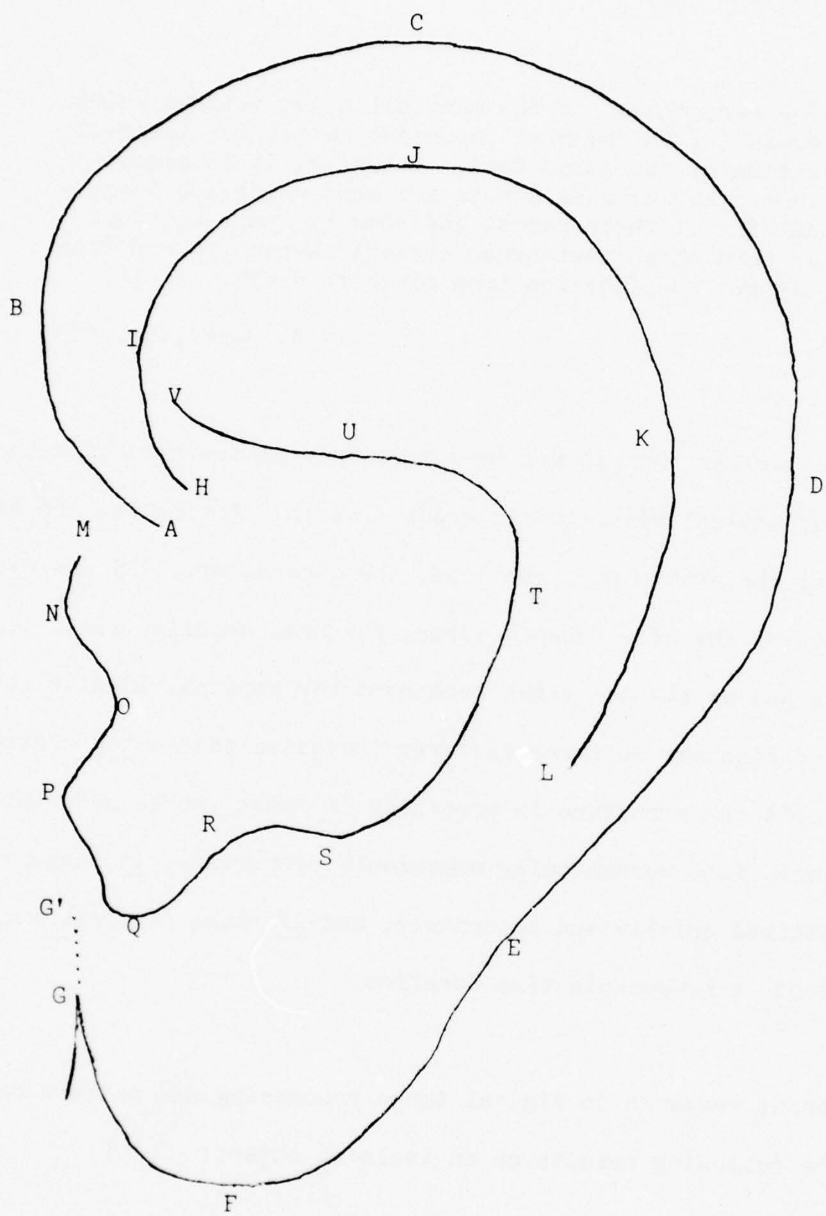


Figure D-4 The Outer Ear

ABCDE: Outer border of the Helix

A: Point of origin

AB: Origination part

BC: Superior part

CD: Posterior part

DE: Inferior part

HIJKL: Inter border of the Helix

EFG: Outer border of the lobe

NOP: Border of the tragus

QRS: Border of the antitragus

VUTS: Border of the antihelix

GG': Adherence

Area within MNOPQRSTUV: concha

Area above VUT and below IJK: fossa innominata

Area between QRS and EFG: the lobe

Figure D-4 The Outer Ear (Continued)

- Object shape can be presented separately as topological properties such as the connectivity, the genus and metric properties such as the curvatures and positions of points of extrema along the object boundary.

- Object color can be measured as grey shades sensed in different spectral bands.

- Object texture can be described as statistical mensurations such as the mean, variance, skewness, etc., of the image spacial distribution.

- Object location can be measured as the distances between the object and two reference points.

The mensuration time depends on the speed in data acquisition and processing. Excluding the human operation time, the former depends on the equipment used. The Computer Eye of Spatial Data System, Inc., for example, requires 34 seconds to digitize a 480 by 512 image and store it on the magtape but only 2.1 seconds if sufficient RAM is available [2]. The data processing time depends on the amount of data acquired, type of measurement used, precision requirement, algorithm adopted and hardware support. The mensuration accuracy depends on sensor resolution, data representation precision, algorithm used, etc., and is biased by the ambient condition and operation procedure during data acquisition and processing.

For each individual, the features cited above are different between the two ears, and vary according to his age, weight, height, physical and mental conditions. Color of the ear, for example, changes drastically when the subject is irritated. On the other hand, the ear is less vulnerable compared with other physiological attributes such as the hand and the foot. According to our preliminary investigation, it seems reasonable to assume that under normal conditions, these features remain constant for adults during a reasonable period of time.

Metric features extractable from the ear include (Figure D-4):

a. The locations of the points A to V

b. The curvatures at these points

c. The distances between point-sets A,H; B,I; C,J; K,D; (width of the Helix)

d. The areas enclosed by E,F,G,Q,R,S (size of the lobe), by M,N,O,P,Q,R,S,T,U,H,A (the size of the concha), by I,J,K,U,V (size of the tassa innominata), M,O,P (size of the tragus), Q,R,S (size of the antitragus)

e. The distances between C,F (length of the ear), B,D (the breadth of the ear) and G,C' (the degree of adherence)

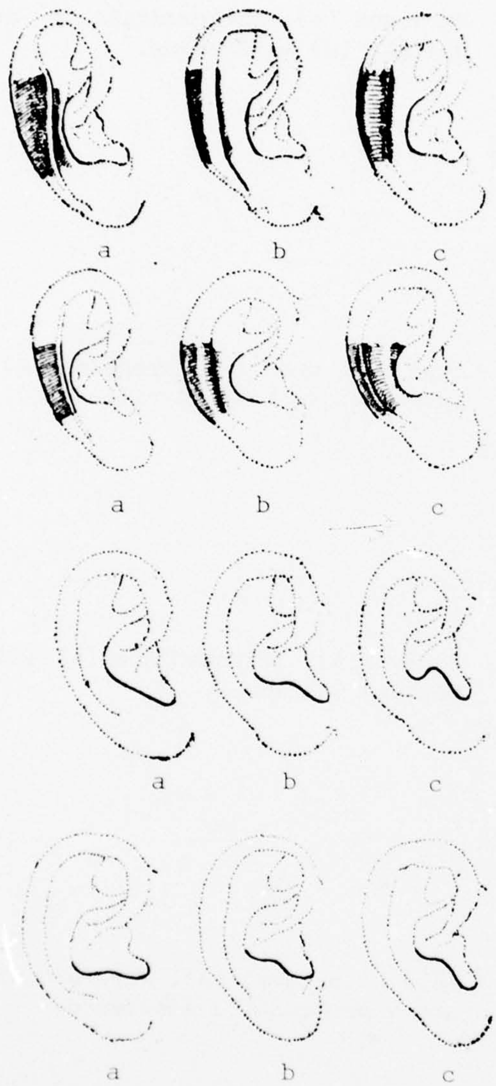
f. The angles between lines $\overline{BG}$ and $\overline{QS}$

It should be noted that some of those points may be unavailable, such as R. Some of these measurements may be linearly dependent and additional independent features can be derived from these measurements. Some qualitative ear descriptions taken from [1] are shown in Figure D-5. From these figures, more metrics can be derived if the sensor is powerful enough.

In the following discussion, the Computer Eye will be used as the input sensor. Considerations will be given centered on this particular system prototype. Suggested equipments are listed in Table D-2.

The size of the human ear seldom exceeds 8.0 cm in length and 5.0 cm in breadth (Table D-3). For 0.5 mm resolution, which is less than one-quarter of the error introduced by manual mensuration [3], the whole ear image can be digitized within a 100 pixel long, 100 pixel wide matrix. For 8 bits/pixel greylevel quantization, it requires 16 K 8-bit bytes to store the data, or about 8 K 16-bit words.

The Computer Eye scanner can scan an image area of 480 lines, 512 pixels per line in $\frac{1}{30}$ second. It takes 51.2 μs for each horizontal scan plus 12.3 μs for horizontal retrace and 2857.5 μs for total vertical retrace per frame. Under the normal digitization mode, the digital computer, under program control, issues the picture location to be digitized. When the scanning spot reaches the location, the light intensity at the location is converted to analog voltage signal. An additional 5 μs is required to convert the analog signal to 8-bit digital values - ready to transfer to the computer. Therefore, 5 μs/(51.2 μs/512) = 50 pixels are skipped horizontally between



Open (a), intermediate (b) and adherent (c) form of the posterior border of the ear.

Lower fold with horizontal profile concave (a), intermediate (b) and convex (c).

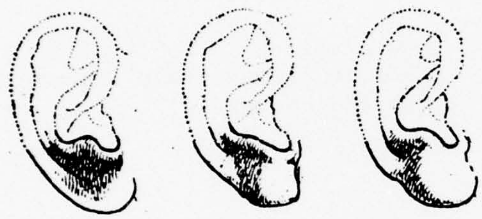
Rectilinear (a), intermediate (b) and projecting (c) profiles of antitragus.

Antitragus with horizontal (a), intermediate (b) and oblique (c) inclination

Figure D-5 Qualitative Ear Feature Descriptions

a b c

Reversed (a), intermediate (b) and upright (c) antitragus.

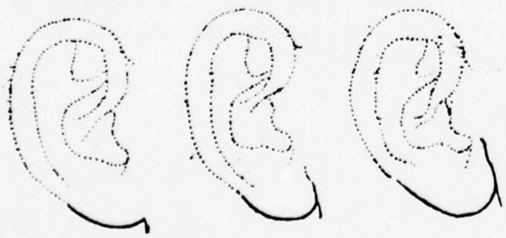


a b c

Lobe with modeling irregular (a), intermediate (b) and raised (c).

a b c

Square (a), intermediate (b) and rounded (c) lobes.



a b c

Lobe with fused (a), intermediate (b) and separated (c) adherence.

Figure D-5 Qualitative Ear Feature Descriptions (cont'd)

1. Computer Eye

    a. Scanner

    b. Display

    c. Digitizer Electronics

2. DEC PDP-11 with 8 K word memory

3. Tape Drive for Data Bank

4. Keyboard/Cursor (optional)

5. Light Source (optional)

6. Mechanical Height Control for Scanner, Light Source, etc. (optional)

Table D-2 Suggested System Equipment for Ear Pattern Extraction

Height (cm)	Ear Length (mm)	Ear Breadth (mm)
165	62	37
166	62	37
167	63	37
168	63	37
169	63	37
170	63	37
171	63	37
172	64	37
173	64	37
174	64	37
175	64	37
176	64	37
177	64	38
178	64	38
179	65	38
180	65	38
181	65	38
182	65	38
183	65	38
184	65	38
185	65	38

50% of the samples fall in between ± 2 mm of the average

90% of the samples fall in between ± 5 mm of the average

98% of the samples fall in between ± 8 mm of the average

Table D-3 Average Ear Size vs. Height from 165 cm to 185 cm Adults (1893)[1]

each data transfer. In order to digitize a 160 by 100 ear image, the image has to be scanned 50 times. Thus, 1.67 second is required if 8 K word high-speed memory is available. (Recommended spacing is 64 pixels skipped. Therefore, 2.1 seconds is required to record the image.)

Assuming each integer addition takes 450 ns and each multiplication takes 750 ns, then it takes 26.4 ms to compute the correlation between two 160 x 100 ear images X,Y based on the formula

$$c(X,Y) = \sum_{i=1}^{160 \times 100} (x_i - y_i)^2$$

where x_i, y_i are intensities at location i in the image X, Y, respectively. Considerable overhead is forseeable for image intensity normalization, proper registration and image fetching from peripheral devices. Nevertheless, 1 second will be sufficient to cover these operations.

If the lineal features such as those discussed previously are to be extracted, then the object has to be isolated first. Typical procedure for object isolation involves edge detection, boundary tracing and encoding, parameter extraction, etc. Assuming the input image is digitized under control, then the operational parameter values should be consistent. Since the whole image is stored in the high-speed memory, processing time should be very short. For instance, it takes 65 ms to compute the gradient.

From the above discussion, the success of personal identification based on the subject's ear structure relies heavily on the image collection process. The ambient luminance, any earring worn by the subject, the color of the hair and clothes, all directly affect the light intensity collected by the sensor. The relative angle between the sensor and the ear surface normal introduces geometrical distortion. The distance between the ear and the sensor and the focus of the sensor should be carefully adjusted to reduce error. How much distortion is tolerable should be studied. Nevertheless, proper registration is desirable at the data acquisition stage to reduce the operational deviations. We propose a procedure in which the subject under test is required to submit some passwords for preliminary identification and ear pattern registration.

Figure D-6 shows those system equipments visible to the subject. The positions of the TV camera and the monitor are fixed on the stand. The heights of the camera, monitor and light source can be automatically adjusted, as can the orientations of the TV camera and the light source. A cursor is attached to the keyboard so that the subject can move the location of a rectangular graph on the TV monitor. The size of the rectangular graph is entered through the keyboard. There are 9 "regions" within the rectangle, as shown in Figure D-7. The subject can select any number in any order of these regions to extract features. Obviously, only the correct person knows the size of the rectangle, the number, the region id's and the order of the regions. Additional information such as the heights of the camera, light source and TV monitor, the orientations of the camera and the light source which are only known to the correct person, can be entered through the

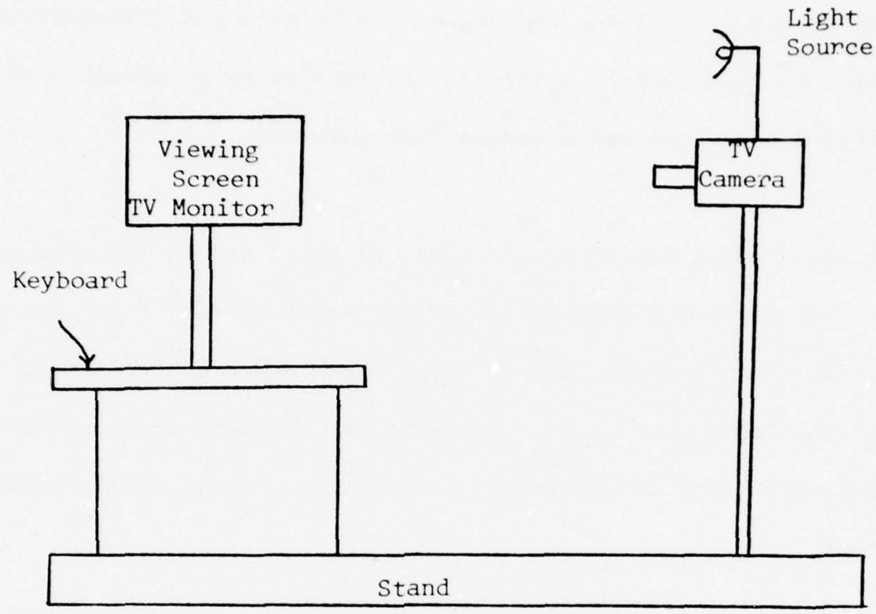


Figure D-6 System Prototype For Ear Structure Attribute Extraction

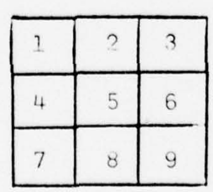


Figure D-7 Nine Regions Within The Rectangle In The TV Monitor

keyboard to increase the difficulty of penetration. It is recommended that the ranges of the size of the rectangle, the heights and orientations, etc., be divided into less than 10 intervals and encoded by 0 through 9 so that the authorized personnel can memorize them with ease.

When the subject is taking the test, he first enters the size of the rectangle, the number of regions in the rectangle, their ID sequence, along with optional numbers such as the heights and orientations of the TV camera and the light source, etc., through the keyboard in question-answering fashion with the computer. These values serve as the password for further test.

The successful subject then registers the ear by viewing the TV monitor. First, he registers his head location relative to the TV camera. Then he focuses the TV camera lens until the image of the ear has similar sharpness as those he takes as "masks" originally. Then he moves the location of the rectangle through the cursor so that the ear is properly registered within the rectangle. Finally he presses the "GO" button for the computer to scan the ear image, digitization and identification.

1. Acceptability: High

Possible objections of using the system are

a. The subject might be requested to pull back his hair to show the ear during the registration.

b. The subject might be requested to take off any earrings.

c. The subject has to memorize the password which is about 10 digits (of a telephone number's length).

d. The subject might be unwilling to show the ear for psychological reasons.

2. Penetrability: Low

a. Pre-screen Phase: The subject has to enter the correct password, which at least consists of the rectangle size code, the number of regions, and the region ID-sequence. Assuming 5 regions were selected, then there are ${}_9P_5$ = 15120 permutations for the ID-sequence. This number, in addition to the 1000 possible combinations of the rectangle length, width and the number of regions selected, reduces the Type II error under 10^{-7}.

b. Computer Identification Phase: technique dependent.

3. Separability: Insufficient Data

4. Cost:

a. Development Cost: If a suitable image processing system is available for use, then development cost in algorithm implementation is

negligible compared to data generation. For 90 subjects, 3 images/subjects estimated processing time will be 2 man-weeks excluding experimental time for proper procedure determinations. The latter will be 3 man-days, conservatively.

b. Purchase Cost: If Computer Eye and associated equipments are available, then purchase cost will be negligible compared to the development cost.

c. Operating Cost: Unknown.

5. Speed:

Should be less than 10 seconds, including data acquisition, and processing.

6. Technology Feasibility: No Problems are anticipated.

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D.10. ELECTROENCEPHALOGRAPHY

Electrical signals produced by the brain were discovered by Caton in 1874. In contrast to the rather simple, strong ($\sim$ mV) electrocardiographic signal, the electroencephalographic (EEG) signals are complex and small ($\sim\mu$ V). The voltages are usually recorded at eight, ten, or even twenty points on the skull, each as a monopolar signal with the ear or neck serving as ground. At first glance the signals appear to be simply band-limited white noise with a cutoff frequency in the neighborhood of 50-100 Hz. Actually, spectral analysis shows the presence of a dominant frequency near 10 Hz for most individuals.

Because the brain is the seat of the intellect, it is tempting to suppose that these brain waves are intimately related to thought processes and that consequently monitoring the EEG would distinguish individuals. Surely our personalities are unique.

> "But individuality remains and it is instructive to consider what it means. Where is my individuality, for example? If I consider this question, it is clear that individuality does not reside to any great extent in my limbs or internal organs, all or most of which can be replaced by protheses or by transplants, or yet in my senses - if I were deaf or blind I would still be me in some sense. But suppose a brain transplant were possible? Transplant *someone else's* brain into "my" body and "I" would not be "me". "I" would now be the other person whose brain now operates in "my" body - it would make more sense to talk about a body transplant." [2]
>
> "A case may be made, therefore, that his memories are the most durable and vital characteristic of an individual." [2]

Unfortunately, the EEG signal is a coarse measure of electrical activity in the brain, being a macroscopic average of the signals produced by billions of individual neurons. According to Gibbs and Gibbs (1950), "Since the electrical activity of the human brain is almost indistinguishable from that of the optic nerve of a water beetle, details of cellular arrangements, important though they are for some purposes, are evidently of secondary importance in electroencephalography." Furthermore, there is no known correlation between EEG at a point of the skull and the function of that part of the brain beneath the point.

On the other hand, EEG signals show important variations with the state of activity of the subject and from individual to individual. In general, the electrical activity which correlates best with changes in central nervous function is the strength of the principal frequency component, although most encephalographers seem to feel that no spectral representation can adequately represent the EEG due to its non-stationary character. The electrical signals of the brain begin during intra-uterine life. The rhythm is slow at birth, but the frequency increases with maturity. It slows again at senility and stops with death. Such effects as sleep, drugs, stage of menstrual cycle, attention, and fright also produce differences in the dominant frequency.

We have stated that the EEG shows inter-individual variations. There appears to be a genetic factor at work here, for the EEG's of identical twins are similar and non-identical twins dissimilar. "But it is not correct to assume that the electroencephalogram is a stable or easily identifiable characteristic of the individual. It is as characteristic as most other body

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attributes; but many persons have EEG's which are practically indistinguishable from those of other persons [1].

In summary, five sets of data have shown important correlations with the EEG: (1) brain metabolism, (2) age, (3) level of consciousness (awake, asleep, relaxed, attentive), (4) certain clinical symptoms, and (5) the pharmacological action of certain drugs. "Only in special types of cases are electroencephalographic changes found to be related to major psychoses, the neuroses, psychopathy, hysteria, emotional disturbances, and intelligence [1]."

Some work has been done to determine whether the EEG might be serviceable for identifying individuals. Rather marginal results were obtained by Bukhout and Walter [3] under controlled conditions. In light of the latter research, the aforementioned variability with state of attention, and the low voltage of the signals involved we consider use of the EEG as a successful entry access discriminant highly improbable.

A related technique, however, would appear much more adaptable to our purposes. It has been observed that the EEG recorded in the time immediately following a stimulus is repeatable. The waveform recorded (usually for 300 - 400 msec after the stimulus) is somewhat unique to the type of stimulus, the intensity of the stimulus, and the individual. It is, moreover, repetitive in time. Since the "evoked potential" is a response to an observer-controlled event, averaging techniques are employed to enhance the signal. A common

stimulus is a flash of light, in which case the waveforms are known as "visually evoked potentials" (VEP). The VEP is roughly ten times the EEG in voltage amplitude.

We postulate that the entrance access control through use of the VEP would require the candidate to clip a ground electrode (dry or capacitative) to his earlobe and view a photic stimulus through a binocular viewing device. The subject's head would depress a second electrode in the frontal position. The VEP of a subject for various light levels would be stored in the system. On any day one of these levels will be chosen at random and the light flashed at irregular intervals. The measured VEP would then be compared with the known VEP for that light intensity and access status determined.

To evaluate the VEP in regard to separability, we may make use of the work of Dustman and Beck [4]. In Figure D-8 we reproduce the VEP of Dustman and Beck for four individuals labeled, D.H., D.F., R.D., and R.W. Each curve for each individual is itself an average of 100 light flashes. The various curves for the individuals were taken at intervals of days and weeks. Thus, long term stability of the VEP is demonstrated. Furthermore, it is obvious from Figure D-8 that there is substantial inter-individual variability. Dustman and Beck sampled the waveform for 300 msec at 25 points. This sampling rate is consistent with other sources which put the typical maximum frequency component in the EEG at 100 Hz. Their data showed an intra-individual correlation ranging from .72 to .99 for seven subjects, with a median value of .88. The inter-individual correlations proved to be much smaller, ranging from -.29 to .92, with median .37. Thus, in the context of Appendix

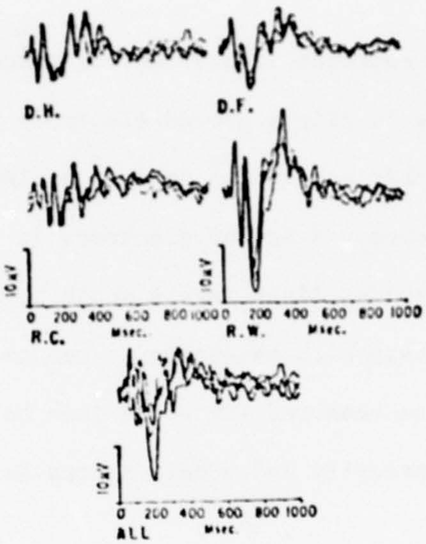

Figure D-8

Reliability and individuality of the evoked potentials. The first four illustrations show the superimposition of four averaged evoked responses recorded at weekly or longer intervals from subjects D.H., D.F., R.C., and R.W. The fifth shows the superimposition of the evoked responses of all four subjects.

B, the dimensionality of the feature space, Λ, is 25, the σ_i values may be taken at 12% of the mean values of the measurements, while the ranges appear to be 63%. Taking E_{II}, the type II error rate as .02, we find from the appendix that for 300 subjects

$$k = \left(\frac{.02}{300} \left(\frac{.63}{.12}\right)^{25} \right)^{1/25} = 3.57.$$

The Type I error rate derived from this value of k is given by

$$(1 - E_I)^{1/\Lambda} = \text{erf}\ (k/\sqrt{2}).$$

This latter equation may be reduced to

$$E_I = \frac{\Lambda}{k^2}\sqrt{\frac{2}{\pi}}\ \exp\ (-k^2/2)$$

for large k and small E_I. Thus

$$E_I = .0027.$$

Consequently, we rate the technique of VEP at 100 in the separability category.

We rate the VEP at 80 in the Technological Feasibility category. The electrode structure would require large modification of existing equipment.

The deve[illegible] costs are apt to be somewhat higher than in the case of the ECG. One wo[illegible] probably begin with standard electrodes and record data on

two channels of an analog tape recorder, as timing and a signal channel. This would be digitized at a later time for signal averaging. The low voltages involved and the time required to develop expertise in the physiological aspects of the problem would both serve to increase costs. Purchase and operational costs do not appear excessive. We rate the VEP at 60 in the cost category.

If 300 msec of VEP are to be examined, the maximum flash rate is .33 Hz. In ten seconds 33 waveforms could be secured for averaging. This number would probably be adequate since the increase in signal-to-noise in going from 33 waveforms to 100 in only $\sqrt{3}$. We rate the speed category at 90.

Because control of the rate and level of the stimulus would be variable, any device for penetration would have to incorporate sensors and would be, in our estimation, quite expensive to build. We rate the penetrability factor at 80.

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D.11. VISUALLY EVOKED MAGNETOENCEPHALOGRAM (VEM)

The oscillating electric potentials of the electroencephalogram which are detectable at the scalp are presumably associated with electric currents in the brain. Recently, magnetic fields of the brain have been discovered. These exceedingly weak fields are thought to arise from the same currents which produce the scalp potentials. Oscillatory magnetic fields of the order of 2×10^{-8} gauss for spontaneous alpha frequencies and of the order of 5×10^{-9} gauss for visually evoked fields have been observed (Brenner, Williamson, and Kaufman, 1975). The typical noise level obtained by these authors in an unshielded laboratory in Manhattan was typically 3×10^{-8} gauss in a band from 5 to 25 Hz.

The study of the VEM has only begun and it is consequently impossible to judge the uniqueness of individual VEM's. It seems a safe assumption, however, that the uniqueness and repeatability of the VEM will be comparable to that of the Visually Evoked Potential. Like the Potential, the VEM is thus of possible interest for individual identification. The advantage of the magnetic technique over the electric is the fact that the magnetic pick-up coil is positioned 2 cm away from the scalp, whereas the Electroencephalographic electrodes must be cemented to the scalp.

The most successful device for detecting weak biomagnetic fields [1,2] employs a superconducting quantum interference device (SQUID). Since a SQUID requires liquid helium temperatures, the cost to operate

an identification access port incorporating a SQUID appears excessive. The state of technology of this device should be re-examined two or three years from now to determine whether advances warrant further study as an identification technique.

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D.12. SALIVA

Saliva collection is relatively easy with a cooperative person and is certainly less obtrusive and non-invasive than blood collection. Since a saliva sample of 0.3 millileters is all that is required for criminal investigations (in wiping saliva from a bite mark), a sample collection well above this minimum can be obtained from a cooperative person by merely having that person spit into a bottle or wipe the tongue with a clean cotton swab. The use of saliva testing required a two-hour laboratory procedure in 1974 but new methods have reduced this to 15 minutes in 1975. Further automated tests could reduce the classification time even further. The end result of a quick test would not likely be a unique identification but rather limited to the classification of human blood types A, B, or O. As in the case of blood, a cellular test examination can achieve a unique identification except between identical twins. The saliva test can, therefore, at best provide one measurement -- blood type -- in a time on the order of 15 minutes. There is no evidence that this time factor can reliably be reduced. Further investigation and tests would be necessary to determine the feasibility of an automatic test of 5 minutes or less.

This attribute is thus considered to have some potential identification capability in the 5 minutes or less time frame that this contract requires but is assigned a secondary roll -- especially since it could probably only contribute to identification by blood group in such a time frame. A longer, more tedious cellular test procedure would be required to attain an individual's identification.

RELATED ARTICLES

1. "Saliva in Forensic Odentology," Journal of Forensic Science Society, 1974, pages 14, 241.

2. "An Improved Test for the Detection of Salivary Amylase in Stains," by G.M. Willett of the Metropolitan Police Forensic Science Laboratory, 109 Lambeth Road, London, SEI 7LP.

3. "A Test Paper for Detecting Saliva Stains," by P.H. Whitehead and Ann E. Kipps, Forensic Science Society, (1975), 15, 39.

D.13. BLOOD COMPOSITION

The uniqueness of an individual's blood has been an accepted belief for centuries. Examination of some of the common traditions and sayings passed from generation to generation give credence to this observation. For example, to sign ones' name in blood is to put an inescapable stamp of individuality on the signature. In the rite of "blood brothers," practiced by many American Indian tribes, the blood (or symbolically the identities) of two individuals are mixed so that they become "one."

The biological identification of blood, however, was slow in coming and it was not until 1901 that any breakthrough occurred. Two major discoveries were made. On February 7, Paul Uhlenhuth announced a method by which human blood could be distinguished from animal. This had profound effect in the field of criminology. The second and probably more important major find was the outgrowth of medical tragedy. Blood transfusions were being pioneered at that time, however, with disastrous results. Nearly half of the patients receiving blood transfusions were dying and it was not until careful autopsies were performed that the reason was found. Death had been caused by the coagulation of the patients' and donors' blood. Dr. Karl Landsteiner pursued this phenomena, and eventually devised a typing or grouping system for blood based on antigen-antibody reactions. This system became known as ABO. The antigens in the ABO system are A and B and the two antibodies

are Anti-A and Anti-B. In Table D-4 we see how the various blood types are described.

The question of whether an individual's blood is unique cannot be answered by application of just the ABO system, for example. Current methodology (in the field of forensic serology) would require the typing of blood by many systems before one could be reasonably sure. To accomplish this, emphasis would, for the most part, be put on the development of the sera and corresponding application techniques required. This is where the difficulty lies, for as Culliford [1] says, "It is not yet possible to individualize blood in the same way as one can a fingerprint, but this is because of a lack of knowledge of techniques and not because of the nature of blood."

Pursuing the question of individuality of human blood, suppose we were required to give only a high probability (possibly 98%) of correctly characterizing one person (by a description of his blood) from a group of others. This is essentially what would be required of most site security systems. To examine whether this problem could be practically solved we first look to population distributions from some of the most common blood typing systems.

The MN and Rh systems are completely independent of the ABO system. The principles, however, are the same - detection of specific blood group features by the agglutination of red cells by specific anti-sera. The

Blood Type (Antigens)	Antibodies to Cause Agglutination	Blood Type Causing Agglutination
A	Anti-A	B or O
B	Anti-B	A or O
AB	Anti-A and/or Anti-B	A, B, O
O (neither A or B)	None	None

Table D-4

population percentages [2] for the ABO, MN and Rh systems are given in Table D-5.

The Kidd [2] system separates the population further, as Table D-6 shows. If a group of people were typed by all four systems, the maximum probability (PMAX) of two people being typed the same would be

$$PMAX = (.44) \times (.27) \times (.32) \times (.51) = .0194 \approx 2\%.$$

Hence, approximately two people in one hundred would be typed the same (again, this is the worst case).

If other systems such as the Kell, Lutheran, and Lewis were added to the previous four, the maximum percentage would drop to about 1%. The possibilities seem quite good that blood typing can yield acceptable Type II errors, and would probably have a very acceptable Type I error rate given adequate implementation techniques. This is further verified by Fisher [2] who arranged the major groups in the order of their inability to distinquish between any two samples of blood. He found the following:

System	Percentage Failure
MNSs	16.4
Rh	19.5
A_1A_2BO	32.8

System	Antigens	Percent of Population(English)
ABO	A_1	35
	A_2	9.5
	B	8.5
	A_1B	2
	A_2B	1
	O	44
MNSs	MNS	27
	MsNs	23
	MMS	21
	NsNs	15
	MsMs	8
	NNS	7
Rh	CDe/cde	32
	CDe/CDe	17
	cde/cde	15
	CDe/cDE	12
	cDE/cde	11
	Others	13

Table D-5

Type	Percent of Population (English)
Jk(a+, b-)	27
Jk(a+, b+)	51
Jk(a-, b+)	22

Table D-6

System	Percentage Failure
Kidd	37.5
Duffy	38.3
Lewis	56.7
P_1P_2p	66.6
Kell	83.7
Lutheran	85.9

Employing all these systems we could expect a probability of .04% that we would not correctly distinguish one person from another. In effect, the preceding statistics serve to emphasize the potential of blood typing as a means of personal identification. Hence, in terms of separability, blood typing would rate approximately 99.

User acceptability of a blood typing security system will be heavily influenced by the means provided for the extraction of fresh blood samples for each of the required tests. Obviously, people will not be receptive to any pain, disease, or infection-causing method. This factor of personal risk and invasion is not overcome by presently available methods. Other possible methods of obtaining blood typing information have been examined. For example, we note that secretors' blood group factors are not only present in blood, but in saliva, tears, persperation, etc. However, secretors [3] make up only 80-85% of the population. Hence, based on the currently available methods, user acceptability would be rated 0.

Other factors also inhibit the use of blood typing at this time. For instance, in a working environment, given that a method of blood extraction was acceptable, the blood would be typed in some automated way. The fresh blood would be collected in a flask of some kind; separated into N smaller flasks (one for each of the N blood typing tests) and input to the machine which would mix each of the N samples with the correct serum. The samples would then move through a precise array of procedures. Ultimately, a reading for each of the N tests would be output. A device called the Autoanalyzer is currently available and works in this manner. It is felt that only slight modification to the machine would be necessary since it is specifically designed to automate the blood typing process. Some interface with a logic device capable of interpreting the output would be necessary. The primary drawback is the high cost of the device.

In summary, blood typing as a means of personal identification holds much promise. However, until sufficient quantities of blood can be obtained easily and acceptably or blood factors can be obtained from other parts of the anatomy from all people, it will probably be unacceptable from the view of user acceptability.

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D.14. ODOR AND SWEAT

Although odor and sweat do appear to have good identification potential, their measurement is extremely difficult and beyond the present state of the art. One easy method used by police today is the use of odor-detecting dogs. The individual's odor can be compared to that of the original by using a piece of the original individual's clothing or a piece of cloth that the individual has handled as a reference.

Scent is transmitted to the cloth by a direct transfer of skin secretions, cells, and bacteria. Cotton gloves would make a good "scent article." Although it may sound silly, a trained dog is worthy of consideration for this personal attributes study because it is not expensive, it is available now, and it is fast in recognizing scent. Also, by making it easy for the dog, using a controlled environment and cooperative individuals to simply put on a pair of cotton or paper gloves, the dog's bark is a positive signal correlation. Trained gerbils are currently being tested for detection of explosives by odor.

Cells within our body have a definite life span, and the epidermis is constantly being replaced. The body odor is produced by bacteria acting upon the dead cells, residues, and body secretions. Added to this activity is the use of toiletry preparations and clothing, and the <u>individual reaction</u> to all of these components. Human odor is undoubtedly very complex and very individualistic. There is probably a basic odor

which is typical of each individual. This, in turn, can likely be varied somewhat by emotions, toiletries, clothing, and diet. These complex interactions alone can account for millions of variations of human odor.

The success in the use of dogs to detect scent is well-known from prior war and police work. German Shepherds, Schnauzers, and Doberman Pinschers are the best known trained dogs.

The measurement of odor by other techniques is still theoretical based on ideas of molecular vibrations in resonant frequency ranges as described in the references to Wright, Davies, Amoore, and Dravmek's theories.

The use of a dog in odor/sweat detection is therefore the recommended solution to this attribute.

RELATED ARTICLES

1. Scent and the Scenting Dog, William G. Syrotuck.

2. Dogs in War, Police Work, and on Patrol, by C.F. Sloane in Police Science.

3. The Science of Smell, by R.H. Wright.

D.15. HEIGHT AND WEIGHT

An individual's height and weight are personal attributes which have long served as crude identification characteristics, serving in applications ranging from driver's licenses to Selective Service records. The fluctuations expected in both these quantities are large and of an obvious source. Nevertheless, together they might serve as a useful zero-order classifier. Furthermore, they are inexpensively and reliably transduced. Finally, we may consider height and weight as prototypes for a long string of crudely measured attributes which, through sheer numbers, meet our criteria. In any case, it is useful to analyze height and weight (HW) as a benchmark against which to compare other techniques. It is educational to analyze HW to see how the formulas developed in Appendix B will apply.

Weight is easily transduced, perhaps through a piezoelectric crystal attached to the "floor" of the access booth. Height could be measured by placing a line of emitter-receiver LED pairs along each side of the booth. The last pair remaining uninterrupted would measure the individual's height.

In Figure D-10, we show a height-weight scatter plot for 64 PAR employees. The plot shows the correlation of large height with large weight that we would expect. The range of the data is an ellipse of "volume" roughly 60 squares, each of area 10 lb-inches for a total volume V of 600 lb-inches. Assuming an individual's weight is apt to fluctuate ± 5 lb due to clothing and the weight variations and ± 2 inches due to heels, the resolution cells are of volume 20 lb-in. Hence, there are roughly 30 bins into which a coarse sorting by height

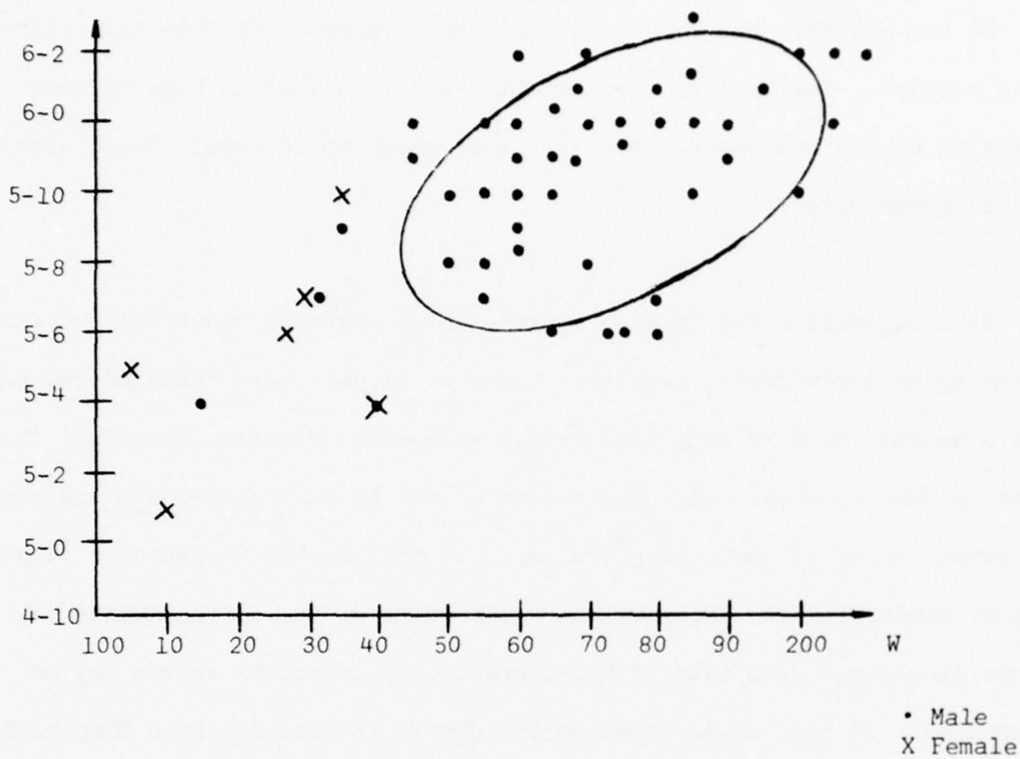

Figure D-10 Height-weight scatter plot for 60 PAR employees. Dots indicate males, crosses indicate females.

and weight would classify individuals. Thus the Type II Error rate of approximately 3% is unacceptable (see Appendix B).

We can estimate the number of additional features of this type that we would require. Taking $\sqrt{30} \approx 5$, we attribute 5 separation bins to each dimension of feature space. Now $5^3 = 125$, which would result in an acceptable Type II Error rate.

As a suggestion for another feature which might prove useful, we consider measuring an individual's density. Since we already have measured the subject's weight, we need only measure his volume to ascertain density. This might be done by subtracting the volume of the access chamber cum subject from the known volume of the access chamber. If the chamber is pressure tight, then by monitoring the pressure and temperature of the chamber while the volume is changed by a (small) known amount, the residual volume may be determined. If this small known volume change is produced by a diaphragm driven sinusoidally at, say 100 Hz frequency, the residual volume should be measurable to high precision.

D.16. GAIT

Gait can be categorized by a crude type of description by observing a person's walk over a distance of 10 to 20 feet. It has been used to identify a person in police work along with other evidence, but it is not easily adapted to computer automation. The human observer can classify gait by posture and style as:

Brisk

Active

Hurried

Slow

Measured

Pompous

Hesitant

Awkward

Shuffling

Limping or Lame

Head: forward, back, to one side

Arms: swinging, hanging, across body

Knees: bent, high stepper, leg swings forward or sideways

Feet: pigeon-toed, splayed out, flat, toe spring

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D.17. ELECTROCARDIOGRAPHY

One of the most well-known bioelectrical signals is the electrocardiogram (ECG). The ECG signal arises from contraction of the heart muscle and is therefore a repetitive waveform with the period of the heart beat. The contraction of the heart muscle, like all muscular contraction, is initiated by an electrical signal carried by the nerves. In the case of the heart, the origin of the signal is the sino-atrial node (under control of the central nervous system), the natural pacemaker of the body. The signal propogates along the bundle of His to arrive at appropriate points of the heart ventricles so as to create a coordinated contraction of the heart. Because of the conductivity of the body's electrolytes, the electrical signal which activates the heart can be detected as voltage differences between points at the body's surface.

There are a variety of systems for electrode placement. Limb leads are attached at both wrists and an ankle while the second ankle serves as "chasis" ground. The six standard chest leads are positioned near the heart. In most present applications, the resistance between skin and electrode is lowered by use of electrolytic paste. One period of a typical ECG is shown in Figure D-11, although the character of the wave will depend upon the electrode pair chosen. The points on the waveform have been denoted P, Q, R, S, and T, with the P wave arising from the atrial contractions, the QRS wave from the main ventricular contractions, and the T wave from the resetting operations required for the next beat. The typical voltages of the R maxima are $\sim$2 mV in the limb leads.

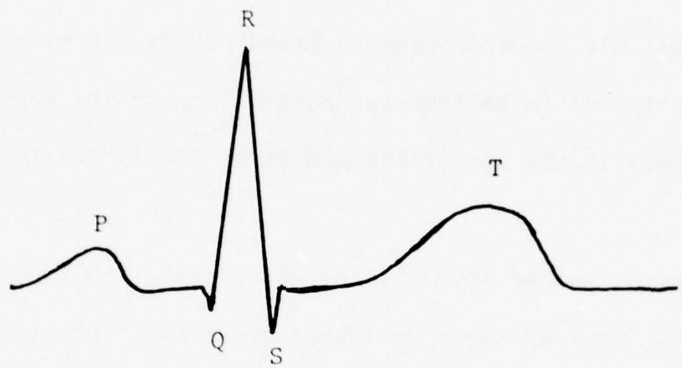

Figure D-11 Typical Schematic Electrocardiographic Waveform in Lead 1.

We now turn to the question of whether an individual's ECG is a unique personal attribute which can be used for identification pruposes. Since the ECG is a clinical tool for the discovery and evaluation of cardiac problems, it has been necessary to study extensively the range of normal ECG's. The individuality encountered is encouraging to the prospects of identification. For example, Burch and DePasquale [1] state that, "The major difficulty in establishing normal electrocardiographic standards is the extreme variability of the electrocardiogram in healthy subjects." One of the early investigators [2] even suggested the use of the ECG as an identification technique!

There is a great number of variables which affect the shape of the electrocardiogram. Some of those variables are associated with physiological attributes of the individual and benefit the identification problem. Other variables will result in day-to-day variations of an individual's ECG and will consequently aggravate the identification problem. In Table D-7, we list the variables in these two categories and appropriate references.

In Section 2.2. we have described our evaluation criteria. The next several paragraphs contain our assignments of numerical values to the criteria for the ECG.

The measurement technique is as follows. Two dry electrodes will be provided to which the subject will touch one finger of each hand. The entrance booth will, in addition, be equipped with a binocular viewing device and touch a third dry electrode to his forehead which will serve as a ground. The electrodes will be pressure sensitive so that data acquisi-

Variables which affect inter-individual differences:

1.	Cardiac Position	[1]
2.	Chest Configuration	[1]
3.	Relative Obesity	[1]
4.	Age	[1]

Variables which affect intra-individual differences:

1.	Digestion	[3]
2.	Respiration	[4], [7], [14]
3.	Baseline Shifts	[4]
4.	Exercise	[5], [6]
5.	Emotion	[10], [11], [12], [12]
6.	Drugs	[8], [9]
7.	Posture	[7]
8.	Electrode Placement	[7]

Table D-7 Variables Affecting ECG's

tion will commence once all three electrodes are depressed. The limb lead ECG between the two hands will be sampled at 100 Hz by a low speed ADC for approximately 3 seconds to record 3 heart beats. The signal will be input to an on-line processor to identify or reject the subject.

In Appendix B, we have already analyzed ECG in regard to its ability to separate individuals with the required Type I and II error rates and we find as a result that the ECG must be assigned a score of 100 in the separability category.

In the category of technological feasibility, it remains only to discuss the dry electrodes we have mentioned, as the amplifiers and other pieces of equipment are "off-the-shelf" items. Two types of dry electrodes have appeared in the literature. One variety makes use of a capacitative coupling in place of a resistive one [15]. The authors report results equivalent or superior to conventional resistive electrodes. Another type of dry electrode is simply a silver electrode attached through circuitry to simultaneously measure, and hence cancel, skin resistance [16]. Neither of these electrodes is, to our knowledge, commercially available, nevertheless the techniques seem well demonstrated so that we have evaluated the technological feasibility at 90.

The cost evaluation category includes development, purchase and operating cost. We estimate that the development costs would be minimal. To build and test the circuits involved in the dry electrode circuit discussed above [16] would require perhaps two weeks of engineering time and two weeks

of technician time. The ADC facility already exists. The purchase and operating cost would largely be reduced to those costs associated with the pattern classification processor. This expense is common to all identification attributes. We consequently rank the ECG at 90 in cost.

Speed of access is a bit of a problem for the ECG. Since one heart beat is always required, the lower bound on the access time is approximately one second. If signal to noise proves a problem, as it well might in such a non-laboratory environment as is here envisioned, then four heart beats will improve the signal to noise by a factor of two; nine heart beats, factor three, and so forth. At the moment there is no reason to believe that more than 3 seconds of data will be required, but the intrinsic 1 Hz rate of the heart beat may represent a boundary at a later time. In recognition of this fact, we have assigned 90 points in the speed category.

The penetrability of our proposed ECG system is perhaps its weakest point. Any technique involving electrodes as transducers is subject to the following penetration strategy. A FM tape recording is made of the ECG of an individual on the acceptance list. The tape recording is played back through the proper impedance matching devices into the electrodes. It seems that the only way to avoid this penetration strategy is to measure other physical attributes simultaneously. On the other hand, the tape recording of an individual's ECG would probably require his cooperation. We assign a score of 70 to the ECG in the penetration category.

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D.18. OTHER TYPES OF CARDIOGRAPHY

There are several other cardiac diagnostic techniques which might be considered useful for extracting personal attributes. All of the techniques we shall mention subsequently are similar in that they measure fluid motion and displacement produced by the beating heart.

Ballistocardiology (Starr and Noordergraof, 1967) employs the fact that the momentum of the blood flowing toward the feet (or any other point of the body) does not equal the momentum of the blood flowing in the opposite direction at every instant of time. To maintain the center of mass of the body fixed, the remainder of the body moves in the opposite direction. The resulting motion is a complicated periodic function which is sensitive to heart stroke, blood volume, timing of the heart valves, blood pressure, etc. The ballistocardiac motions of the body can be observed by anyone standing on a sensitive spring scale and has consequently been rediscovered more than once in the history of medicine since J.W. Gordon produced the first ballistocardiogram (BCG) in 1877.

The ballistocardiogram is affected by many of the same variables listed in Table D-7 for ECG's. According to Starr and Noordergraaf (1967) height, weight, body volume, age, sex, respiration, digestion, drugs, and emotion are all important considerations. Consequently, we may expect substantial inter-individual dispersion, as in the case of ECG. Indeed, "Records of healthy persons do show small differences from one another, and these differences are

so characteristic that the senior author soon learned to identify his friends by a glance at their records" (Starr and Noordergraaf, 1967).

Although modern ballistocardiography requires the patient to lie on a table with sensitive (usually air) bearings, a usable record may be obtained from a subject in a vertical position. Building vibrations must be reckoned with in the latter case as the amplitude of the motion is greatly reduced. For the BCG employed as an entry access control, we envision an entry booth with floor entirely composed of a bearing platform. The motion of the platform must be damped to avoid initial oscillations when the subject enters the booth. The mechanism must then be unlocked and rapidly brought to a sensitive state.

For ballistocardiography, it has not been possible to find the detailed inter- and intra-individual variation statistics similar to those employed for evaluating ECG's because of the relatively small number of institutions utilizing the BCG. Nevertheless, it seems reasonable to argue from analogy with ECG's that the BCG should score 100 in the separability category.

In regard to user acceptability, we note that the BCG requires no electrodes. On the other hand, the subject will be forced to cooperate to the extent of remaining motionless and perhaps hold his breath for the duration of the measurement, several heartbeats at least.

To promote the BCG access control to the status of technologically feasible requires a large modification of existing equipment to convert the

presently available table devices into a platform. The locking mechanism which will be engaged when the subject enters the access port and the mechanism for adjusting the platform to equilibrium under the subject's weight remain to be developed. We rate the BCG at 70 in the technological feasibility category.

The development cost of the BCG is apt to run into hundreds of thousands of dollars since data collection will require purchase of a commercial BCG unit. The purchase cost will also be much higher than for ECG since the contemplated unit would be a special production item. Operating costs appear reasonable. We rate the BCG at 70 in the cost category.

It seems that the BCG access control technique may be expected to require approximately 5 seconds. Two seconds are allotted for bringing the platform to equilibrium and 3 seconds to record three heart beats. We rate the speed category at 90.

The BCG is quite interesting in its impenetrability. Suppose an intruder builds a device capable of simulating the accelerations of a person on the acceptance list. First of all, this would be a rather sophisticated device. Secondly, the intruder would be forced to remove his own BCG signal from the platform, perhaps by elevating himself off the floor by a rod attached between the walls of the access port. We might expect such abnormal behavior to be easily detectable. We rate the BCG at 90 in the penetrability category.

Phonocardiology is simply electronically assisted auscultation. The motion of the blood and the openings and closings of the heart valves produce sounds which are picked up by a microphone attached by pressure to the chest. Again, in relation to ECG, very little quantitative information is available as to the variations found in the normal population. Two facts, however, are pertinent. On the plus side we note that the phonocardiogram (PCG) contains frequency components up to 1000 Hz so we might expect a higher dimensionality of feature space than the ECG. The principal drawback of PCG is the sensitivity of the record to placement of pickup microphone and to the acoustic coupling achieved between microphone and chest. We recommend that the PCG not be utilized over the ECG due to the many variables which it seems difficult to evaluate without further experimental data.

The same remark applies to an even greater extent to echocardiography and displacement cardiography. Echocardiography employs ultrasound and records the time-varying acoustic properties of the chest through the heart cycle. Displacement cardiography likewise records the time varying velocity of the heart and tissue of the chest in response to the cardiac cycles. The displacement cardiograph utilizes an oscillating magnetic field and measures the inductance changes produced by moving tissues. Both of these cardiographic techniques would be quite sensitive to the position of the subject and rather expensive to develop. Consequently, we feel that neither can be competitive with ECG and we eliminate them from consideration.

D.19. QUESTION AND ANSWER (Q/A) SYSTEMS

The system to be described here is derived in part from suggestions by Martin [1] in connection with computer terminal security procedures. As the user signs on, the computer asks the user a sequence of personal questions. Questions have been selected in such a way that only the authorized user knows the correct answer, and which he is not likely to forget. (This will reduce the tendency of some users to write down the correct answers in a diary or notebook, where they might be stolen. This is a serious objection to the usual passwords or security code.)

Martin gives the following examples of questions which might be employed: "When is your wife's birthday?, What is the first name of your grandmother?, What is your Aunt Mary's maiden name?" The computer selects a small number of such questions from a larger number stored for that person. It need not ask the same questions each time, so that another person could not obtain all the correct responses by looking over his shoulder or tapping the telephone or other linkage.

He concludes: "This sign-on procedure has the advantage of being easy to use, but the disadvantage of being somewhat lengthy in operation. It does not give a high degree of security if the questions are such that a persistent intruder could find out the answers to them, as with the first two questions above."

The advantages to a question-and-answer (Q/A) system would be the following:

1. The user is not required to carry any objects, such as keys or cards, which might be lost or stolen.

2. The correct responses are easily remembered, in contrast with number sequences or code words.

3. "Off-the-shelf" equipment, in the form of inexpensive alphanumeric terminals, is readily available at a low price.

Disadvantages, as noted by Martin, include the "somewhat lengthy" time required for entry, and the possibility that a persistent intruder may be able to obtain the answers to some personal questions.

In addition, the following objections should be considered: if a large number of questions are to be available to the system, the storage requirements may become excessive. A Q/A system may also encounter resistence from personnel who may feel that personal privacy is being invaded. (For example, a request for the names of relatives may reveal ethnic origins which the individual properly feels are irrelevant to his employment.)

The purpose of the following discussion is to show that these objections can easily be met by a Q/A system.

It is important to emphasize, first, that individual memory uniquely identifies an individual (Locke, 1653). If it is correct to say that no two persons have the same set of memories, however, it is essential to establish some sort of behavioral criterion for determining whether individual A actually possesses the set of memories which he claims.

The problem is a non-trivial one in many legal applications, where it is essential to establish, for example, that a claimant is actually the missing heir. Childhood memories may be sufficient to establish the claimant's identity.

For the purposes of personal identity verification, however, two constraints will pose serious problems:

First, the limited storage capacity of any reasonable computer-based system will require that the system use only a very limited number of questions, which must further be restricted to those which can be checked by the machine. (*This would eliminate, for example, a qualitative description of the individual's childhood home, for which the data would be far too rich for effective machine storage and checking.*)

Second, another person, who may be assumed to be a persistent, malicious intruder, may be able to memorize enough facts about the person to be able to answer a sufficient number of questions correctly.

Thus, while it is undoubtedly true that an individual's memories are unique, it is not true that an individual's behavioral responses cannot be imitated by another person.

The system to be described here is intended to meet the preceding objections.

A very simple terminal would be sufficient for the Q/A system, consisting of a keyboard with alphanumeric characters, a visible display, and a non-volatile random-access memory. Because of the relatively high cost of CRT displays, it may be suggested that a single line of LED characters be employed. However, for cost comparison purposes, a small CRT is used (below).

Memory requirements could be reduced significantly if personnel carried magnetically-encoded cards. Such cards would include correct answers to a variety of questions, which would be sufficient to identify the person authorized to carry the card. However, the use of cards would violate one of the constraints imposed upon the identity verification system, and other means would be required for storage of verification data.

It is proposed that a very limited number of questions be stored, and that the questions be modified at each entry. Thus, the data for any individual person will be changing constantly, reducing the likelihood that a persistent intruder will be able to memorize a set of correct responses.

The proposed dialogue might take the following form:

NAME ? CLIDE SAMUELS

DOG'S NAME ? BARKLEY

MOTHER'S FIRST NAME ? BETTY

ENTER FATHER'S FIRST NAME = DICK

PASS

The first entry is used to retrieve records concerning the named person. If no such name appears in the file of cleared persons, admission is denied and an alarm sounds.

The next two entries are retrieved at random from the individual's records. These are stored as pairs of questions and responses. Further research will be required to determine an ideal number of pairs to be stored; for the purposes of this description, we may suppose that about ten Q/A pairs are stored for each individual on an inexpensive random-access device within the secure area. If a mismatch is detected, an alarm sounds.

Finally, the system requests a new entry, father's first name. This is a random selection from a stored list of possible queries, and it is used to replace one of the Q/A pairs already appearing in the individual record. The new pair will be available for identification for subsequent entries.

To avoid the problems of personal privacy mentioned earlier, and to make it much more difficult for imposters to obtain the correct responses, it

should be made clear to users that they need not tell the truth in their initial answers. The unmarried person may, for example, tell the system that her spouse's name is PRINCE CHARMING. The only requirement of the system will be that she uses the same response whenever the system asks for her spouse's name. In this way, no person would ever be required to enter information which he or she regarded as a potential invasion of personal privacy.

An additional advantage to this procedure would be that a potential intruder could not possibly discover the correct responses for any individual, since no one other than the individual would know those responses. (It is assumed that hardware storage devices and connecting cables are maintained in a vaulted area.)

For the purpose of cost comparison with other personnel varification systems, a relatively small computer terminal is described in the attachment. The cost of this equipment is in the $1,000 to $2,000 range. Since it incorporates a small CRT screen, which is a relatively expensive item, the cost of this terminal may be regarded as higher than that of one which includes a less sophisticated form of display. However, an advantage to this terminal is the ability to display complete instructions for the novice user, messages in case of user error, etc. In addition, since it is rack-mountable, it may be made relatively secure against tampering by mounting it into the wall of a passageway near the secured entrance.

It is reasonable to estimate that time required for the use of this Q/A system will be less than 30 seconds for the experienced user (who does not

require initial instructions and is familiar with terminal operation.) For such a user, the time involved will be the time required to type four or five words in response to system queries.

It is expected that the Q/A system will easily meet requirements for Type I and Type II errors.

In estimating the probability that an intruder is capable of guessing the correct reply to a query, it is necessary to select a typical query; probabilities will vary somewhat with the type of query. Consider the query MOTHER'S FIRST NAME ? Webster's New World Dictionary lists approximately 400 women's names under the heading "Common Given Names," without including variant spellings. Although no distribution data is included, it is reasonable to suppose that a person who guessed the most common name on the list would have no more than 1 chance in 100 of being correct. This chance would be considerably reduced if users were encouraged to substitute mythical names for their mothers; strange or exotic names would be much more difficult to guess.

If n questions are asked, the probability of guessing all n questions correctly will be 100^{-n}. Thus the probability that an unauthorized intruder would guess three questions correctly would be 10^{-6}.

The likelihood that an authorized person will enter an incorrect response is also quite small. If the terminal is mounted in such a position that only the user can see the display, it should be possible to echo the user's entries as they are keyed in. The user will thus be able to proofread his entry

before entering it into the system, which will mean that typing errors will be infrequent. The only possible source of error will thus be the result of the user's forgetting the correct response. Since questions will deal with very familiar material, this likelihood is quite low.

There is an obvious risk that a person who is cleared for a particular area may reveal information to an uncleared person, thereby permitting him to penetrate the security system.

Although such a possiblity obviously exists for a Q/A system, it is no greater than the risk that <u>any</u> cleared person will reveal classified information to an unauthorized person. The whole existence of clearance procedures is founded upon the assumption that a cleared person will not reveal classified information (within limits of risk which are narrower as the clearance level is higher).

It is important to emphasize this point. If a person holding a security clearance were to reveal the correct responses to the Q/A system to an unauthorized person, he would be guilty of revealing classified information and would be prosecutable under appropriate regulations. Moreover, he would be very likely to be identified as the guilty party, since only he would have known the particular responses which were revealed.

Under these conditions, the risk of penetration of the Q/A system is no greater than the risk that any cleared person will reveal classified information to an unauthorized person. Moreover, the risk that an unauthorized

person will be able to obtain the memorized responses to the Q/A system is considerably lower than the risk that he will be able to make voice recordings, to duplicate fingerprints, or to obtain other surrogates required to penetrate systems which depend on physical characteristics.

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D.20. TYPING STYLE - KEY SEQUENCE TIMING

Typical access security methods often require the subject to state his identity. It seems quite reasonable that the current project will do the same and that the statement will be made via keyboard to be machine accessed.

The hypothesis of this proposal is that measurable differences in the speeds which occur during typing can be used to verify the stated identity.

A primary advantage to this method is that little or no additional hardware is required and the software is very simple. Data collection is implemented by code which intercepts signals from the terminal (keyboard) and extracts timing information. The signal is passed on to normal processing unchanged.

Preliminary data collection should require roughly 1 man/week to implement and roughly 1 week for collection.

Preliminary evaluation:

1. Separability - unknown until data becomes available. The fact that telegraphers can be distinquished by their particular style, the so-called "fist," which must be timing

characteristics plus the recognition of personal cadence and habits in typing supports an expectation of entirely sufficient separability. Rate (tentative) 50.

2. Acceptability - rates 100 if a statement of identity via keyboard is assumed. Perhaps only 90 if special keyboard activity is required.

3. Equipment - assuming statement of identity, no additional equipment should be required. Rates 100.

4. Cost - it is not clear how to give a relative rating to cost here but, as mentioned in the description of initial implementation, cost should be quite low. Rating 85.

5. Speed - no delay is caused the subject. Analysis should certainly be within 3 seconds. Rating 100.

6. Penetrability - a device for penetrating this method has been suggested, an array of solenoids placed over the keyboard and driven by a recording of the proper person's activity. Rating 50.

A program has been written to run on the PDP 11/45 which measures the time delay between keystrokes on the console. This program has

been used to gather statistics which would permit a tentative evaluation of the consistency and uniqueness of an individual's typing style. It was considered most likely that, if any repeatable pattern were to exist at all, it would be most strongly displayed when the subject typed a familiar character string such as his name. Five subjects were requested to type their names and the names of the other individuals taking the test. The results for the typing of the name "David Bennett" by David Bennett are tabulated in Table D-8. The first column of the table gives the adjacent character pairs in the name. The second column gives the time delay (units = 5 milliseconds) mean and standard deviation for the subject on day A, the second column gives these numbers for David Bennett on day B two weeks later. This data shows that the pattern of the subject's typing remains rather constant over two weeks. In Table D-9 we show the results of an imposter typing the name "David Bennett." Finally, Table D-10 gives the mean delays for five subjects typing "David Bennett." Table D-10 also lists the standard deviations of the subjects (interindividual variation) multiplied by $\sqrt{3}$ to convert to an equivalent uniform distribution. The between-subject variation, σ_B, is consistently larger than the within subject variation, σ_W. In fact, the mean of σ_B/σ_W is 4.08. Assuming that there are typically 10 character pairs in a name, we compile the estimated Type I and II error rates given in Table D-11. (Refer to Appendix A).

	Trials of Day A		Trials of Day B	
	Mean	Standard Deviation	Mean	Standard Deviation
DA	25	8.12	23	2.67
AV	26	7.61	22	6.67
VI	29	10.13	26	3.65
ID	43	6.10	42	9.11
D_	56	18.42	43	7.76
_B	46	23.7	44	7.70
BE	20	3.35	25	1.78
EN	25	3.39	25	6.73
NN	31	1.10	31	.85
NE	28	11.26	26	3.44
ET	26	7.76	26	3.93
TT	33	5.26	33	4.66

Table D-8 David Bennett typing "David Bennett"

	Trials of Day A		Trials of Day B	
	Mean	Standard Deviation	Mean	Standard Deviation
DA	18	2.82	20	1.63
AV	42	8.85	27	2.77
VI	73	9.59	71	15.26
ID	64	17.3	55	3.79
D_	72	8.2	61	11.65
_B	69	20.36	70	10.21
BE	19	2.28	23	4.73
EN	90	37.36	53	20.32
NN	32	2.19	30	2.82
NE	42	22.69	46	16.5
ET	38	16.15	40	7.9
TT	39	19.69	26	2.24

Table D-9 Imposter Typing "David Bennett"

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	$\sqrt{3}\sigma$
DA	27	56	45	18	25	27.12
AV	39	93	49	42	20	46.58
VI	26	73	55	68	29	37.67
ID	38	88	52	54	41	33.99
D_	52	120	36	72	83	55.18
_B	57	136	106	83	46	63.38
BE	47	67	55	19	20	36.82
EN	32	121	62	90	25	69.28
NN	29	48	27	32	31	14.50
NE	40	73	38	42	28	29.50
ET	48	83	45	38	26	37.03
TT	31	45	35	39	33	9.68

Table D-10 Five Subjects Typing "David Bennett"

Tolerance Parameter k	E_I	E_{II}
1.5	-	.0045%
2.0	-	.08%
2.5	12%	.75%
2.828	4.6%	2.6%

Table D-11 Type I and II Error Rates for $\Lambda = 10$ and $\frac{\sigma W}{\sigma B} = 4.08$

D.21. LIPS

Lip prints consisting of labial wrinkles and grooves have been divided into 8 types by individual quailoscopy for personal identification [1]. Moreover, there was found to be an individual specificity in the morphology of the lip grooves. In a sample of 107 females, no one individual had the same lip groove pattern as any other. Lip prints were taken in the same manner as fingerprints using a lipstick or other removable cosmetic on the lips. Lip prints could also be taken by photography of a magnified TV camera. Lip prints of 280 individuals were taken and found to be different. Lip prints of 18 pairs of unovular twins indicate that lip prints of twins are extremely alike and their characteristics are inherited either from the father or mother. A study of lip prints over time was being carried out in 1970 but the results are not yet appeared.

This method holds promise as a prime consideration in personal attributes identification. Lipstick on women does not prevent but is an aid to its use. The correlation of an individual's lip prints could be matched in a similar manner to fingerprints. One method may be to have each individual kiss a clean glass plate (if wearing lipstick) or a coated glass (if not wearing lipstick). The comparison could then be made to his filed lip print by a TV camera magnification of the new lip prints against the original.

To aid in the alignment of the lip prints and thus improve the computer-aided response time, a TV viewer could aid the individual in aligning his lip print with the original on a TV monitor using the original as a ghost overlay.

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D.22. POLYGRAPH

The Lie Detector Test is only 80% to 100% accurate depending on the individual being tested and the operator's ability and questioning techniques. It measures breathing, blood pressure, pulse, and sweating.

The use of a "truth serum" is objectionable as a drug since it must be injected slowly into a vein of a willing person. It is therefore not considered for the purposes of this study.

The polygraph machine, using respiration and blood pressure measurements, has attained an accuracy of verified diagnoses (using the Reid questioning method employing disguised and undisguised questions) of over 99% successful. A new method, called the "silent answer test", reduces defects caused by oral answers. If the GSR (Glavanic Skin Reflex) is used with the silent answer procedure, the results are enhanced in reliability and accuracy as compared to using each separately.

The main objection to the polygraph is not its accuracy or reliability but its discomfort factor. As in the case of blood pressure measurements, the polygraph requires the use of a blood pressure cuff and pneumograph tube which may cause a pain reaction or discomfort. Moreover, the procedures are time-consuming since they require sufficient questioning to mix control questions as a reference to "peak of tension" questions.

Body movements and unnecessary oral discussion by the subject have disturbing effects on the tests. Data in 4000 cases is available.

RELATED ARTICLES

From Police Science Journal:

1. A Critical Analysis of the Theory, Method, and Limitations of the "Lie Detector." by Benjamin Burack, Vol. 46, 1955.

2. The Polygraph Silent Answer Test, F.S. Horvath and J.E. Reid, Vol. 63, 1972.

3. Truth Serum, by John W. MacDonald, Vol. 47, 1956.

4. Interpretation of Blood Pressure Rises, by Richard Arthurs, Vol. 47, 1956.

D.23. HUMAN BODY TRANSFER FUNCTION

The physiological and psychological uniqueness of one person from another has probably always been evident to man. From the earliest evidences of art we see a careful depiction of the variations in human form.

One of the basic questions in medicine, for example, is how does man as an individual respond to various external stimuli. For example, the human body's response to vibration. The answer to that question is just beginning to be realized, however, the essence of today's solutions goes back to research begun in 1862. In that year Dr. Maurice Raynaud wrote an MD thesis describing the symptoms and probable origin of a disease effecting the extremities. As he described ".. persons, who are normally females, see under the least stimulus, sometime without appreciable causes, one or many fingers becoming pale and cold at once." The disease, then known as "dead fingers", was later given the name Raynaud's phenomenon, and it was at that time thought to be largely hereditary in origin.

By the end of the nineteenth century, other conditions giving rise to Raynaud's disease were recognized. The increased technology at the turn of the century allowed the production of many new hand-held vibrating tools, such as the pneumatic drill. The vibration induced by these tools had, under certain conditions, effects similar to those described by Dr. Raynaud. It was further found that the disease tends to be permanent unless only slight damage has been inflicted on the fingers.

The level of vibration at which damage is produced in the hand as well as which causes general discomfort and loss of efficiency is difficult to determine. The ISO (International Organization for Standardization) has done much to try to determine what are the acceptable limits of vibration intensity and duration with respect to frequency. Attempts to mathematically predict how man will react to certain vibrations have, for the most part, rested upon the ability to accurately model the human body. In particular, to model it as a linear discrete or continuous mechanical system.

Research [1] has shown that for some frequencies, the human body can be modeled as a linear, lumped parameter (discrete) system. This is important since it now enables us to apply much of the well formulated linear systems theory to the analysis of human body response. Lumped mechanical systems are composed of springs, masses and dampers. The parameters do not vary with time and behave in a linear manner. In Figure D-12 there is illustrated a simple discrete, one degree-of-freedom system.

Then, if the system is excited by a function, $F(t)$, it has a response, $x(t)$, which is completely determined by the system characteristics. If the variables, $F(t)$ and $x(t)$, are transferred from the time or t domain to the s domain we get (for initial conditions equal to zero)

$$G(s) = X(s)/F(s)$$

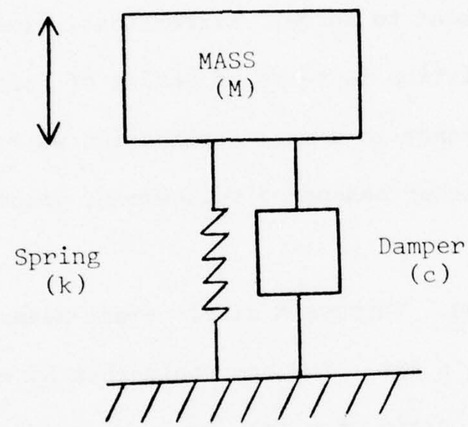

Figure D-12

where G(s) is the system transfer function. Further, for s=jw (where $j=\sqrt{-1}$ and w = radian frequency) we can re-express the transfer function in terms of frequency as

$$G(jw) = X(jw)/F(jw).$$

This equation expresses the complex frequency response of the system in terms of the ratio of displacement to force. Expressions, similar in concept may express system characteristics in terms of ratios of force-to-velocity or force-to-acceleration. Hence in a real application we may attach transducers to body segments which either measure displacement, velocity, or acceleration.

An example is offered. Suppose a displacement-measuring transducer is attached to an individual's arm. The arm would then be excited by a sinusoid of varying frequency; the ratio of output to input would be recorded, and the phase angle measured. Then, with all this necessary information given, the transfer function for the arm would be synthesized. From the following data we can construct a Bode plot (Figure D-13) from which the transfer function G(s) can be found. The slopes of the plot of output/input vs. frequency can provide information as to the type of terms present in the transfer function.

W rad/sec	Output/input (dB)	Phase lag (between output and input)
.1	19.9	-101.2
.2	13.6	-112.3
.5	4.08	-137.0

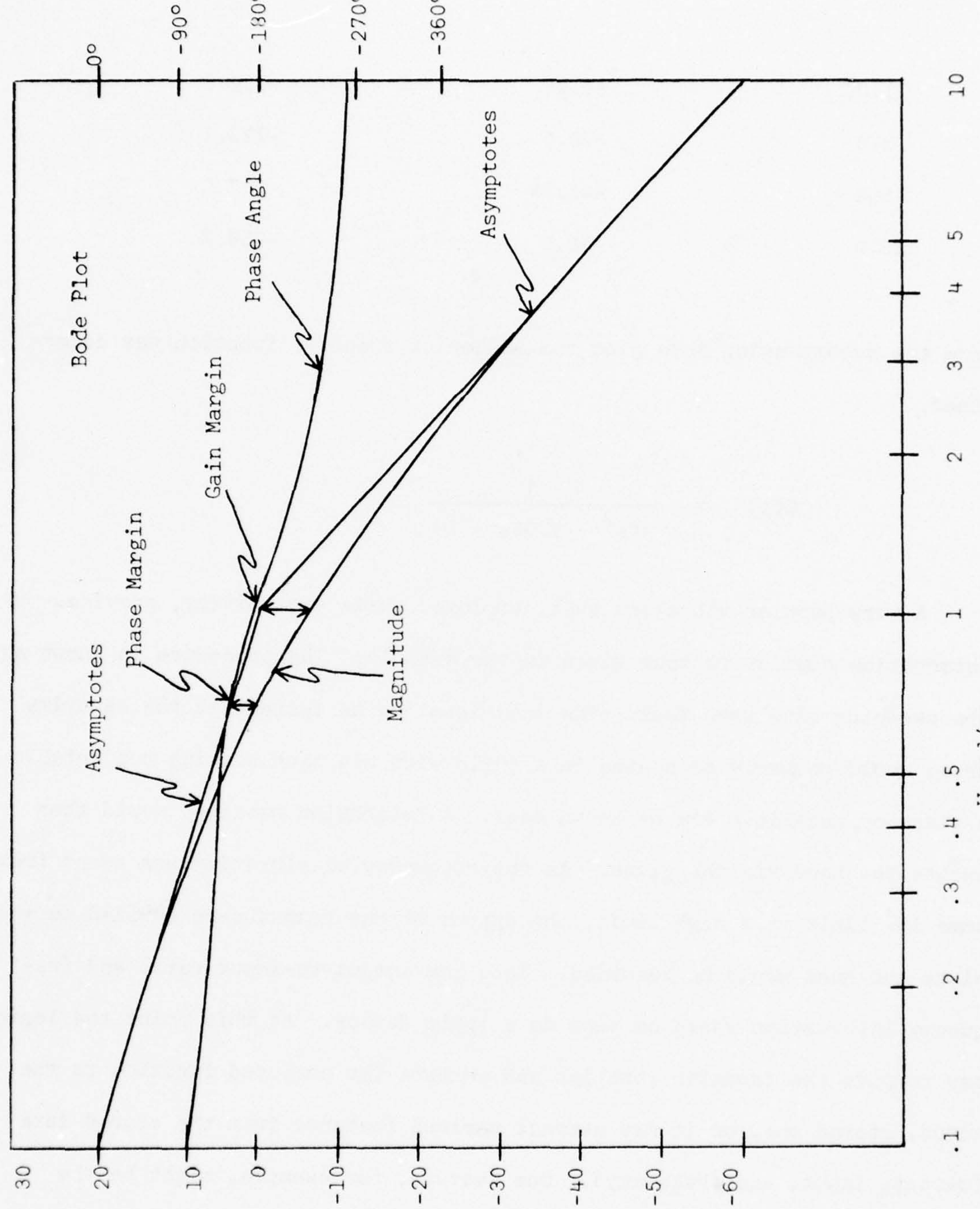

Figure D-13 Bode Plot Used to Determine the System Transfer Function

1.0	-6.02	-180.0
2.0	-20.0	-223.1
5.0	-41.94	-247.8
10.0	-60.0	-258.7

From the accompanying Bode plot the following transfer function was determined.

$$G(s) = \frac{1}{s(s^2 + 1.96s + 1)}$$

A very popular vibration test, employed quite extensively, provides information similar to that given in the example. The procedure is known as the sweeping sine wave test. The individual to be tested, at the security area, would probably be seated in a chair with his hand resting confortably on a glass or metalic plate of known mass. A "vibration machine" would then excite the hand via the plate. As the frequency of vibration was swept from some low limit to a high limit, the output of the transducers coupled to the plate and hand would be recorded. Then the output-to-input ratio and frequency information would be sent to a logic device. At this point the logic may compute the transfer function and compare the computed function to the known, stored one, or it may extract various features from the stored data (output, input, and frequency). One feature, for example, might be the location, in frequency, of resonant conditions.

User acceptability of a vibration-inducing security system will be heavily influenced by the discomfort and apprehension generated by the vibration and test equipment. For transfer function measurements of the hand-arm, a plate and attached transducer could be used, without requiring the user to don any electrical hardware. This would probably be acceptable. The amplitude of vibration could be troublesome if it is too large. This may cause discomfort. Testing would probably have to be done to determine what amplitudes of vibration are acceptable to a wide range of people. Essentially, if the hand-arm system is employed, user apprehension and discomfort should be in an acceptable range. User acceptability is rated 90.

The effective implementation of any identification system relies heavily on the availability of the necessary measurement devices. Equipment to be used in body transfer function measurements could essentially be selected from "state-of-the-art" vibration test hardware. Equipment development in vibration testing has kept pace with the demands of many fields, hence, there is a wide assortment of highly accurate, relatively inexpensive hardware available. Most, if not all, of the equipment needed in a body transfer function security system would be of the "off-the-shelf" type so there should be little need for any extensive equipment modification or development. This type of security system should be technically very feasible, hence, is rated 100 in that area.

It is a reasonable assumption that the human response to vibration will be a function of not only the body characteristics but also of certain test conditions. The variables involved may be grouped as extrinsic and intrinsic features depending on whether they are characteristic of the vibrational input

or the human body. Some extrinsic variables [2] affecting the vibration response of the body are the

1. Frequency range of vibration
2. Amplitude of vibration
3. Time history of vibration
4. Direction of vibration
5. Point of application of vibration
6. Interaction between the body and vibration input
7. Effect of clothing, etc.

The hand-arm system, for example, should be subjected to vibrational frequencies that offer the best opportunity of determining uniqueness between individuals. M.J. Griffin [2] has stated that "It would appear to be a reasonable proposition that resonances at higher frequencies are highly characteristic of an individual such that even when a particular frequency has a significant effect on one subject, there is frequently no such overall effect for a group of subjects." Let us pursue this observation further. One researcher, James Ott [3], has patented an "individual identification apparatus and method using frequency response." He has essentially used spectral information from 900 Hz to 6000 Hz. To measure the vibrational response of the hand-arm he attaches a transducer to the skin in the immediate area of the ulna bone. This may be a source of significant variability in the vibration measurement for as Suggs [4] has pointed out, "Because of the resiliency of the skinx and muscle, surface attachment of vibration transducers is not feasible except in the low frequency range (Abranam and Suggs, 1969). For higher frequency observations

it is desirable to attach transducers directly to the bone." It <u>is</u> desirable to measure transmission through the bone because it is the most rigid tissue of the arm. Bone attachments are obviously, however, impractical in an identification system.

What we are saying then is that although an individual's response to vibrational frequencies above 900 Hz (or so) may be unique, the ability to reliably and consistently obtain this information may be seriously impaired by the inability to directly measure it.

The other extrinisc factors are important but to some degree can be reliably controlled. For example, the dynamic response of the hand-arm is likely to be quite different along different axes. However, we can solve the problem by measuring vibration response along only one axis (most likely the longitudinal).

The intrinsic variables are probably most responsible for the variablity in response between individuals. Some of the more significant intrinsic factors are

1. Body size (weight, height, etc.)
2. Posture or physical peculiarities (deformities)
3. Body tension

Body posture would probably be most influential in whole body response measurements (not the hand-arm). However, what of body size? We know that

body size may, in whole body tests especially, effect the dynamic characteristics of the vibration source, but for the hand-arm, this type of effect should not be significant. What body size may be most indicative of is the mass of the bone, muscle and other tissue for each individual. Hence, because these components of the body will, to some degree, always be unique to each person, the response of the hand-arm, for example, should be somewhat unique for each subject. Zaveri and Phil [5] have shown the response characteristics of two people to be uniquely different. One person weighed 55 kg and the other 80 kg and both were subjected to the same test conditions.

Body tension can also effect the transmission of vibration to the body. For example, tests [5] conducted in which subjects were required to hold a vibrating handle showed that the amount of grip pressure was directly related to the force transmitted through the arm. For tests measuring mechanical impedance (force/velocity), there was an increase in the impedance for higher grip forces.

In conclusion, the dynamic response characteristics of the hand-arm or, for that fact, body segments in general are probably dependant on the basic psysiological characteristics of the individual as well as the psychological factors which can influence them. The masses of individual arms will be different; subjects will on any given day be tense or relaxed, or the muscles may be stretched or bunched from some previous physical activity. Hence, there are many very important and influential factors effecting the reliability with which a security system, using body transfer function information,

can operate at. There is no available information nor data available in sufficient quantity which would enable us to predict either the Type I or II error rates. For separability, we rate the attribute 60, primarily because of the degree of variablity which the user can input to the system.

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D.24. FINGERNAIL AND TOENAIL STRIATIONS

The examination of nail samples has been shown to be an important criminological tool in recent years. Like the patterned "friction skin" of the hands and feet, the longitudinal striations (grooves) of the nails apparently do not change with age, and in many criminal cases have afforded a means of establishing the guilt or innocence of a suspect [1,2]. However, permanent disfigurement of the nails can result from a serious injury or disease. The striation process is caused by the nails being "extruded" over parallel ridges on the nail bed during growth. These ridges are sufficiently numerous and randomly distributed to preclude the existence of two identical striation patterns, thus providing a means of personal identification. Fingernail samples acquired from the same subject over a period of ten years did not show any marked variation [2].

Inasmuch as the striations of the lower, concave surfaces of the nails are more pronounced than those observed in vivo, known studies have required the removal of at least a portion of the nail, usually a clipping. The undersides of specimens are preferred also because they are somewhat protected from damaging wear and injury during their lifetime. On the average, the spacing of the striations is of the order of .1 mm, so that approximately 100 lines per nail are available for comparison [3].

Three methods of preparing specimens are currently in use. The first involves simply flattening them in a press after cleaning. Two nails at a time are then viewed under a comparison microscope at 24-52 times magnification. The second method is designed to increase the resolution through the use of a metalizing step that dramatically improves the contrast between the striations when examined by microscope. The third method produces color images of nails placed between two sheets of crossed linear polarized material and observed under a comparison microscope. No known techniques for studying the nails in vivo have been developed.

The prospects for establishing a personal identification system based on the nails, preferably the fingernails, appear to be promising, provided that a suitable means of measuring the striations be devised. This might entail applying a temporary coating to the nail as part of a photographic technique, or developing a highly sensitive transducer for detecting the occurrence of the striation peaks. Such an instrument could then be used to examine a nail in much the same manner as a UPC reader scans a bar code.

Accordingly, the technological feasibility of measuring nail striations has been assigned a score of 60. The separability and identification speed are each worth 100 points, but less than total acceptability of the system could be anticipated, since women users would be prohibited from applying nail polish. Also, the possibility of

an intruder wearing counterfeit or stolen nails would render the system vulnerable to penetration.

In summary, nail striations appear to offer an attractive alternative to presently accepted criteria for personal identifications. But because it is not feasible for clippings to be taken each time a subject is to be screened, current methods of analysis are inadequate. It is felt that further research is needed to ascertain the viability of a personal identification system based on the nails.

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3. Thomas, F. and Baert, H., "The Longitudinal Striations of the Human Nails," <u>Journal for Medicine</u>, 14 (July-Sept, 1967) pp. 113-117.

D.25. ULTRASONICS FOR HAND BONE STRUCTURE

The arrangement of bones in the hand can be observed easily via x-rays. Ultrasonic techniques coupled with laser imaging have been used to see fine skeletal detail in a living fish [1]. Be replacing the optical imaging arrangement with an array of ultrasonic sensors, an arbitrarily fine digital image (up to sonic wavelength resolution) should be produced.

The primary feature measured is the relative locations of finger joints because they are fairly regular and will show up more clearly than other features. Features such as shapes of finger bones, placement of palm or wrist bones all involve much more complexity and potential interference than just fingers and so would be ignored.

Preliminary evaluation:

1. Separability - the variations in the measured feature are seen to be rich by simple observation so separability should be adequate even after the requisite data scaling and orientation.

2. Acceptability - the subject will get a wet hand or will have to insert the hand into a possibly threatening device. It is possible that he will hear noise indicating ultrasonic activity which may also be a deterrent.

3. Equipment - no complete device as required here is known to be readily available but all necessary components are either "off-the-shelf" or easily constructed.

4. Cost - a nearly complete cutfit is required, at least in prototype form, even to gather Phase II data. Since this is considered a development cost, this factor rates about 30.

5. Speed - Rates 95. Digitization of the sensor output, scaling, orientation, and filtering (to leave only joint locations) should be on the order of milliseconds. In all, 12 items of numeric data will then be compared to the data base. Time should be well within 10 seconds even for a larger installation.

6. Penetrability - duplication, to the expected resolution of this system, of the internal structure of a particular person's hand would be especially costly and difficult for an adversary so the rating is about 80.

REFERENCES

1. Goldberg, B.B., et al. Diagnostic Uses of Ultrasound, New York: Grune and Stratton, 1975, p. 27.

APPENDIX E

ALGORITHM FOR EXTRACTING "C-TRACE" MEASUREMENTS

```
      SUBROUTINE EKG(W1;V1)
      VECTOR V1(10)
      DO  30 I9•1,10
      LET V1(I9)•0.
   30 CONTINUE
      LET F1•SP(W1)
COMMENT  NEL R-WAVE LOCATER---LOOK FOR TYPICAL R-WAVE; THRESH IS I90
      LET I1•NPT(W1)
      DO  15 I19•1,5
      LET I90•7000-1000*I19
      LET I50•.2*F1
      IF  (I1<.9*F1)LET I50•.05*F1
      LET I81•W1(I50)
      LET I82•W1(I50+2)
      LET I83•W1(I50+4)
      LET I84•W1(I50+6)
      LET I85•W1(I50+8)
      LET I86•W1(I50+10)
      LET I87•W1(I50+12)
      LET I88•W1(I50+14)
      LET I89•W1(I50+16)
      DO  1 I9•I50+18,I1-I50,2
      LET I81•I82
      LET I82•I83
      LET I83•I84
      LET I84•I85
      LET I85•I86
      LET I86•I87
      LET I87•I88
      LET I88•I89
      LET I89•W1(I9)
      IF  (I81>I82)GOTO 1
      IF  (I82>I83)GOTO 1
      IF  (I83>I84)GOTO 1
      IF  (I84>I85)GOTO 1
      IF  (I85<I86)GOTO 1
      IF  (I86<I87)GOTO 1
      IF  (I87<I88)GOTO 1
      IF  (I88<I89)GOTO 1
      IF  (I85-I81<I90&I85-I89<I90)GOTO 1
      LET I10•I9-8
      LET I50•I85
      GOTO 2
    1 CONTINUE
   15 CONTINUE
      GOTO 50
    2 CONTINUE
      IF  (I50>W1(I10-1))GOTO 25
      LET I10•I10-1
      LET I50•W1(I10-1)
      GOTO 22
   25 CONTINUE
      IF  (I50>W1(I10+1))GOTO 22
      LET I10•I10+1
      LET I50•W1(I10+1)
   22 CONTINUE
COMMENT  I10 IS LOCATION OF R-WAVE; I50, AMPLITUDE
```

Figure E-1

```
COMMENT
COMMENT STEP BACK I4 POINTS FROM I10 TO SEARCH FOR P-WAVE;
COMMENT WINDOW END IS I10-I5
    LET I4=.18*F1
    LET I5=.05*F1
    LET I15=I10-I4
    LET I20=I10-I5
COMMENT SEARCH I15,I20
    LET I99=0
10 CONTINUE
    LET I99=I99+1
    IF  (I15<1)LET I15=1
COMMENT QRS COMPLEX TOO CLOSE TO BEGINNING OF WAVEFORM
    IF  (I20<1)GOTO 50
    LET I11=I15
    LET I3=W1(I15)
    DO  3 I9=I15+1,I20
    LET I2=W1(I9)
    IF  (I2>I3)LET I11=I9
    IF  (I2>I3)LET I3=I2
 3 CONTINUE
    IF  (I11>I15&I11<I20)GOTO 5
    IF  (I11=I15)LET I8=(3*I15-I20)/2
    IF  (I11=I20)LET I8=(I15+I20)/2
    LET I20=I20-I15+I8
    LET I15=I8
    IF  (I99<2)GOTO 10
 5 CONTINUE
    LET I35=I3
COMMENT I11 IS LOCATION OF P-WAVE MAXIMUM; I35, AMPLITUDE
COMMENT
COMMENT STEP FORWARD I6 POINTS FROM I10 TO SEARCH FOR T-WAVE;
COMMENT WINDOW END IS I10+I7
    LET I6=.18*F1
    LET I7=.3*F1
    LET I15=I10+I6
    LET I20=I10+I7
COMMENT SEARCH I15,I20
    LET I99=0
11 CONTINUE
    LET I99=I99+1
    IF  (I20>I1)LET I20=I1
COMMENT QRS COMPLEX TOO CLOSE TO END OF WAVEFORM
    IF  (I15>I1)GOTO 50
    LET I12=I15
    LET I3=W1(I15)
    DO  4 I9=I15+1,I20
    LET I2=W1(I9)
    IF  (I2>I3)LET I12=I9
    IF  (I2>I3)LET I3=I2
 4 CONTINUE
    IF  (I12>I15&I12<I20)GOTO 6
    IF  (I12=I15)LET I8=(3*I15-I20)/2
    IF  (I12=I20)LET I8=(I15+I20)/2
    LET I20=I20-I15+I8
    LET I15=I8
    IF  (I99<2)GOTO 11
 6 CONTINUE
```

Figure E-2

```
      LET I36=I3
COMMENT I12 IS LOCATION OF T-WAVE MAXIMUM; I36, AMPLITUDE
COMMENT
COMMENT MOVE BACKWARD FROM I10 TO SEARCH FOR Q-WAVE; CHECK
COMMENT FOR CHANGE IN SLOPE
      LET I21=W1(I10)
      DO  7 I9=2,I10
      LET I19=I10-I9+1
      LET I22=W1(I19)
      IF  (I22>I21)GOTO 8
      LET I21=I22
    7 CONTINUE
    8 CONTINUE
      LET I13=I19+1
COMMENT I13 IS LOCATION OF Q-WAVE MINIMUM;I21, AMPLITUDE
COMMENT
COMMENT MOVE FORWARD FROM I10 TO SEARCH FOR S-WAVE
COMMENT CHECK FOR CHANGE IN SLOPE
      LET I23=W1(I10)
      DO  9 I9=I10+1,I1
      LET I24=W1(I9)
      IF  (I24>I23)GOTO 12
      LET I23=I24
    9 CONTINUE
   12 CONTINUE
      LET I14=I9-1
COMMENT I14 IS LOCATION OF S-WAVE MINIMUM;I23, AMPLITUDE
COMMENT
COMMENT MOVE FORWARD FROM I14 TO SEARCH FOR S'
COMMENT LOOK FOR CHANGE IN SLOPE
      LET F15=0.
   72 CONTINUE
      LET I67=W1(I14)
      LET I48=W1(I14+1)
      LET I74=I14+.06*F1
      DO  19 I9=I14+2,I74
      LET I24=W1(I9)
      IF  (I24-I48<F15*(I48-I67))GOTO 29
      LET I67=I48
      LET I48=I24
   19 CONTINUE
      LET F15=F15+.1
      GOTO 72
   29 CONTINUE
      LET I47=I9-1
COMMENT I47 IS LOCATION OF S'; I48, AMPLITUDE
COMMENT
COMMENT   FEATURES:
COMMENT   1 P-Q INTERVAL
COMMENT   2 Q-R INTERVAL
COMMENT   3 R-S INTERVAL
COMMENT   4 S-S' INTERVAL
COMMENT   5 S'-T INTERVAL
COMMENT   6 (P-Q AMP)/(R-Q AMP)
COMMENT   7 (R-Q AMP)/(R-S AMP)
COMMENT   8 (T-S' AMP)/(R-Q AMP)
COMMENT   9 (S'-S AMP)/(R-S AMP)
COMMENT  10 (R-S AMP)/20000.
```

Figure E-3

```
    LET V1(1)=(I13-I11)/F1
    LET V1(2)=(I10-I13)/F1
    LET V1(3)=(I14-I10)/F1
    LET V1(4)=(I47-I14)/F1
    LET V1(5)=(I12-I47)/F1
    LET V1(6)=(I35-I21)/(I50-I21)
    LET V1(7)=(I50-I21)/(I50-I23)
    LET V1(8)=(I36-I48)/(I50-I21)
    LET V1(9)=(I48-I23)/(I50-I23)
    LET V1(10)=(I50-I23)/20000.
    VCEND V1
 50 CONTINUE
    RETURN
```

Figure E-4

APPENDIX F

CARDIOGRAMS OF SUBJECT A

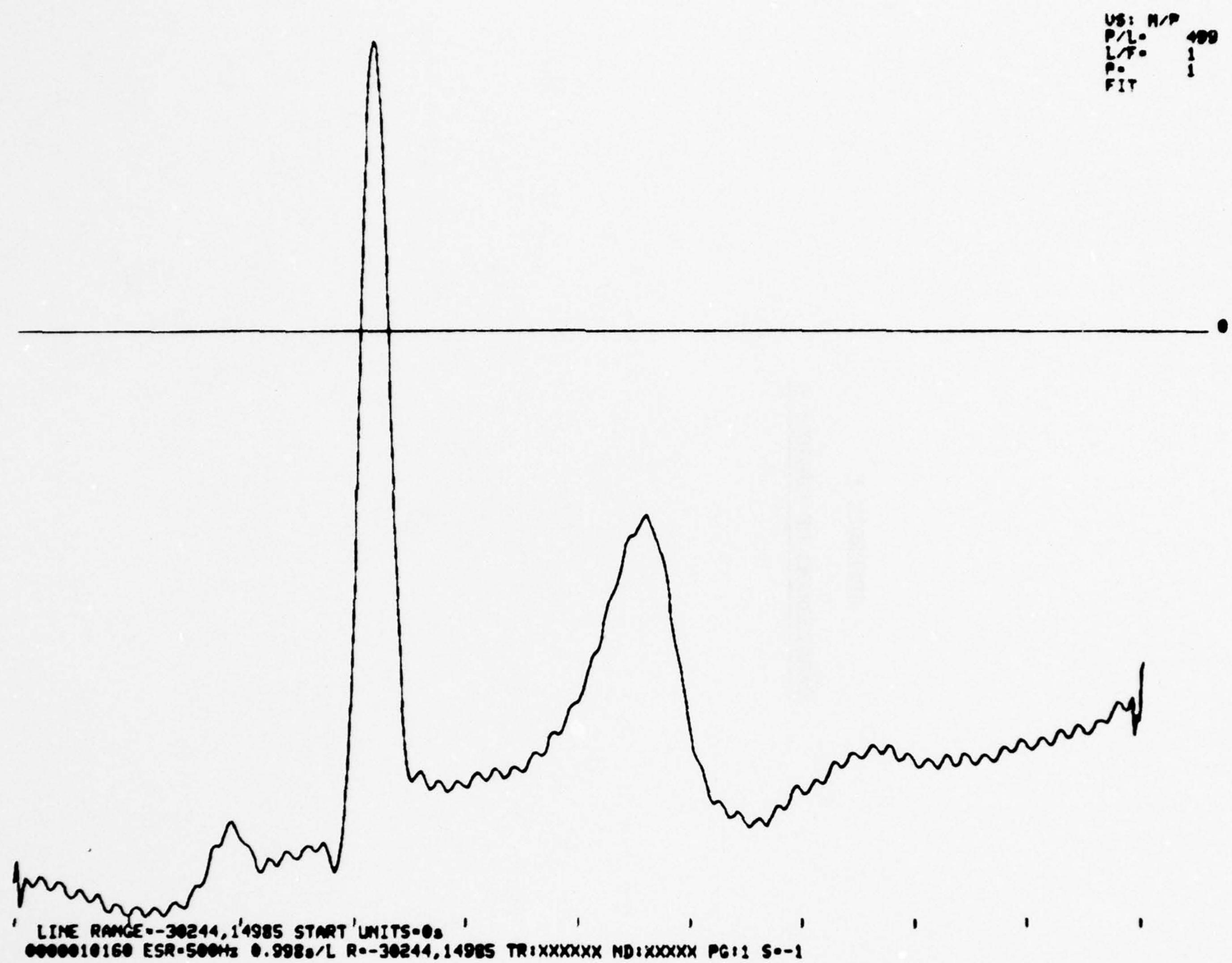

VS: M/P
P/L= 499
L/F= 1
P= 1
FIT
LINE RANGE=-30244,14985 START UNITS=0s
0000010160 ESR=500Hz 0.998s/L R=-30244,14985 TR:XXXXXX ND:XXXXX PG:1 S=-1

Figure F-1

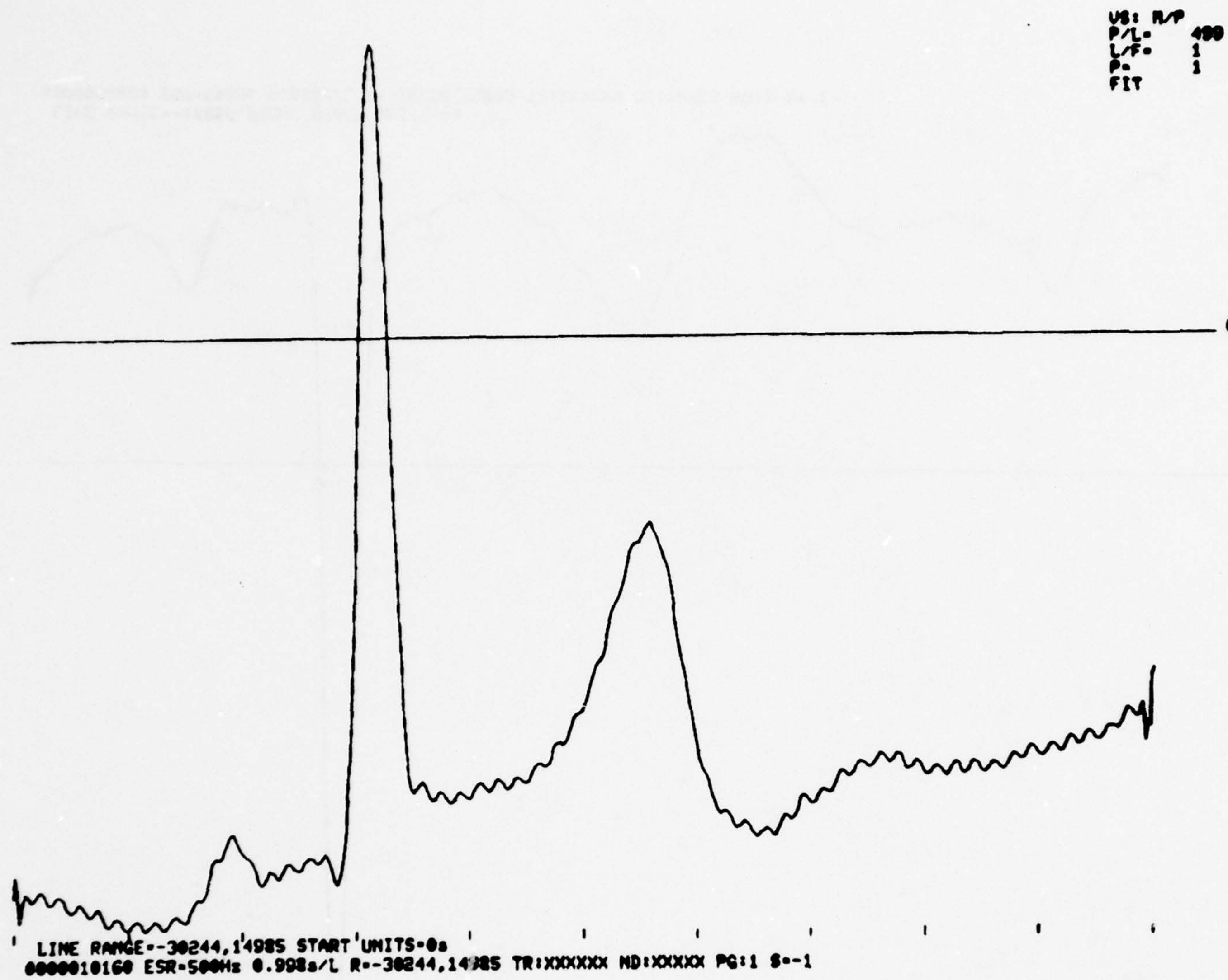
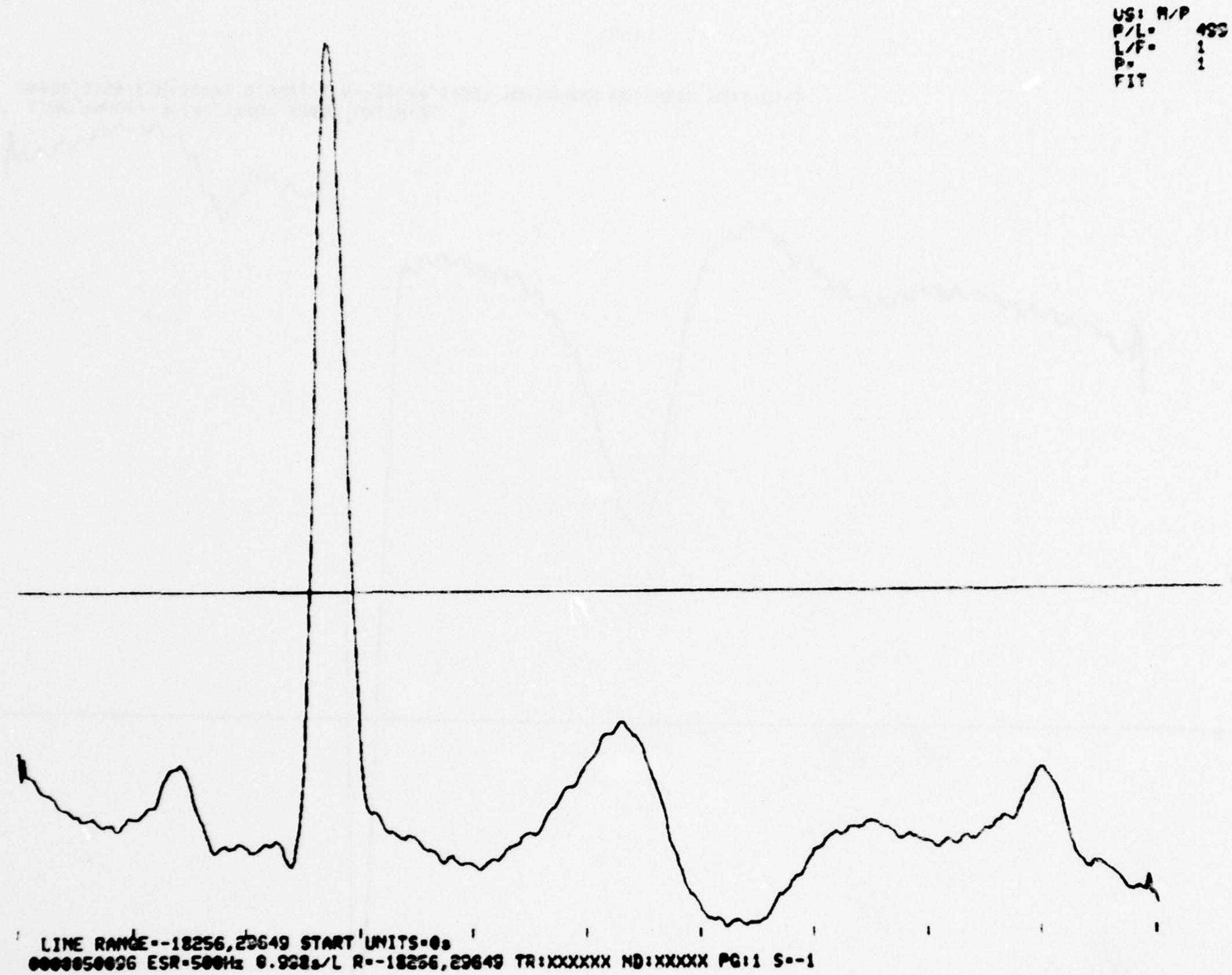

VS: A/P
P/L= 400
L/F= 1
P= 1
FIT
LINE RANGE=-30244,14985 START UNITS=0s
0000010160 ESR=500Hz 0.998s/L R=-30244,14985 TR:XXXXXX ND:XXXXX PG:1 S=-1

Figure F-2



US: M/P
P/L= 493
L/F= 1
P= 1
FIT
LINE RANGE=-18256,29649 START UNITS=0s
0000050096 ESR=500Hz 0.928s/L R=-18256,29649 TR:XXXXXX ND:XXXXX PG:1 S=-1

Figure F-3

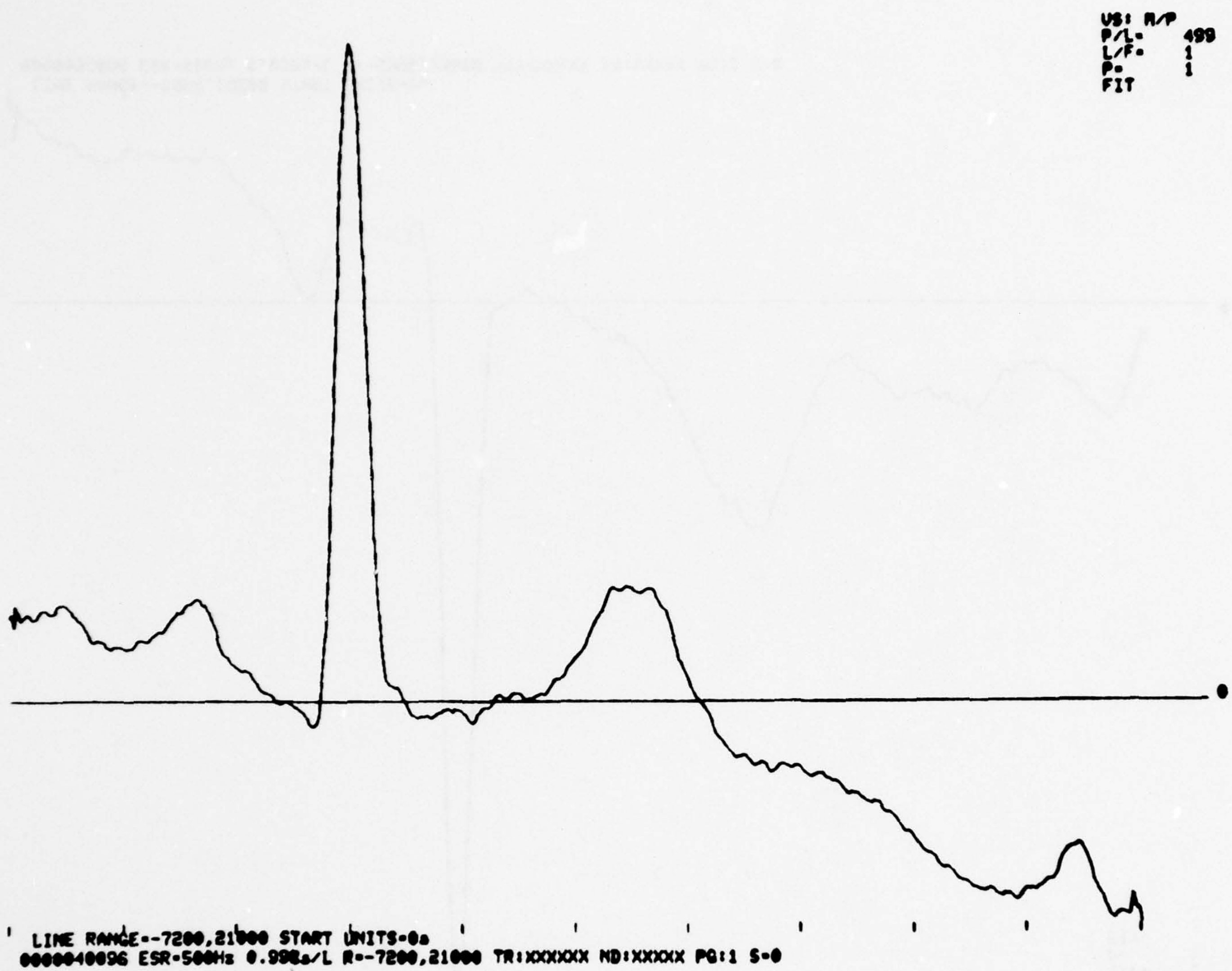

VS: A/P
P/L= 499
L/F= 1
P= 1
FIT
0
LINE RANGE=-7200,21000 START UNITS=0s
0000040096 ESR=500Hz 0.998s/L R=-7200,21000 TR:XXXXXX ND:XXXXX PG:1 S=0

Figure F-4

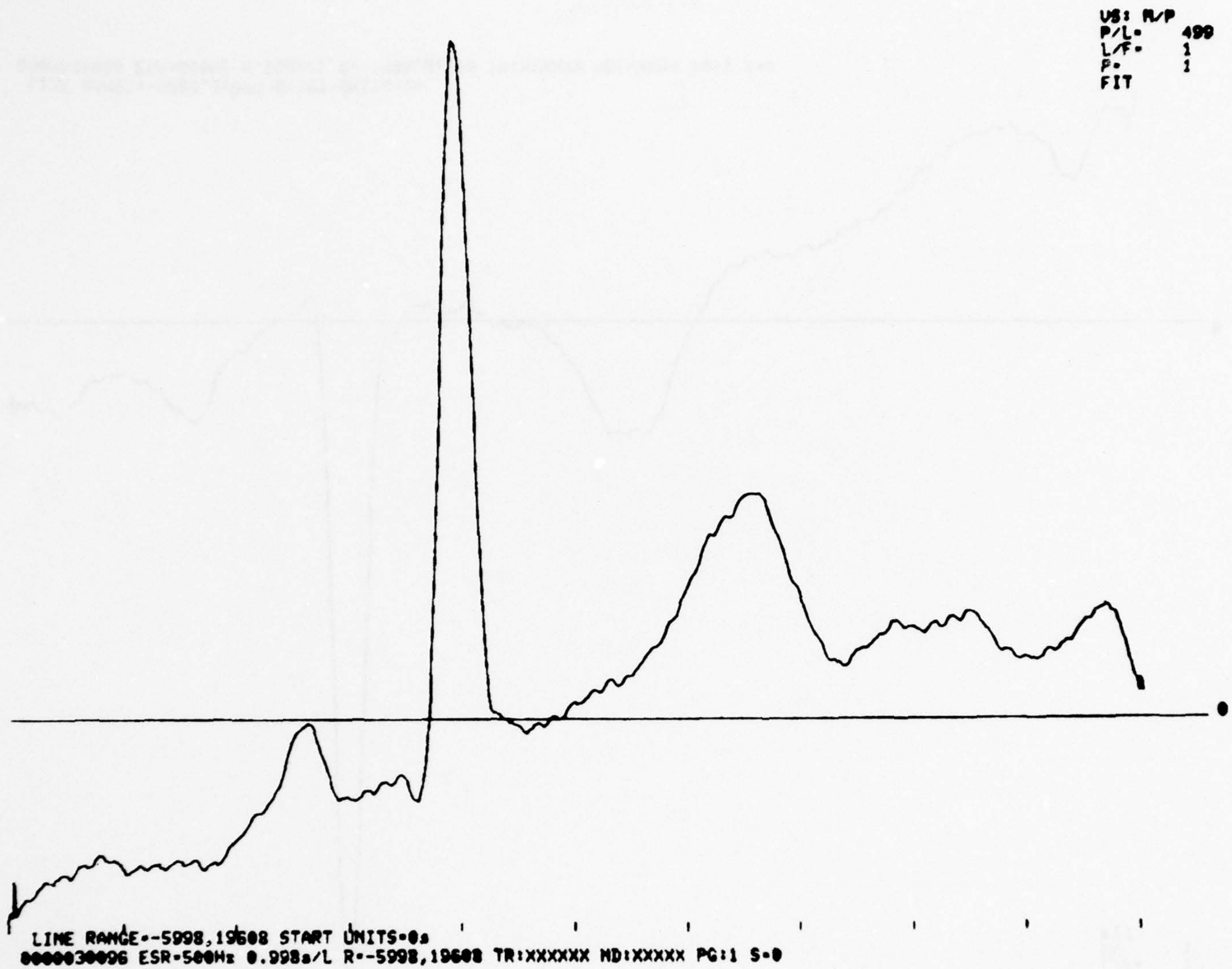

VS: R/P
P/L= 499
L/F= 1
P= 1
FIT
LINE RANGE=-5998,19608 START UNITS=0s
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Figure F-5

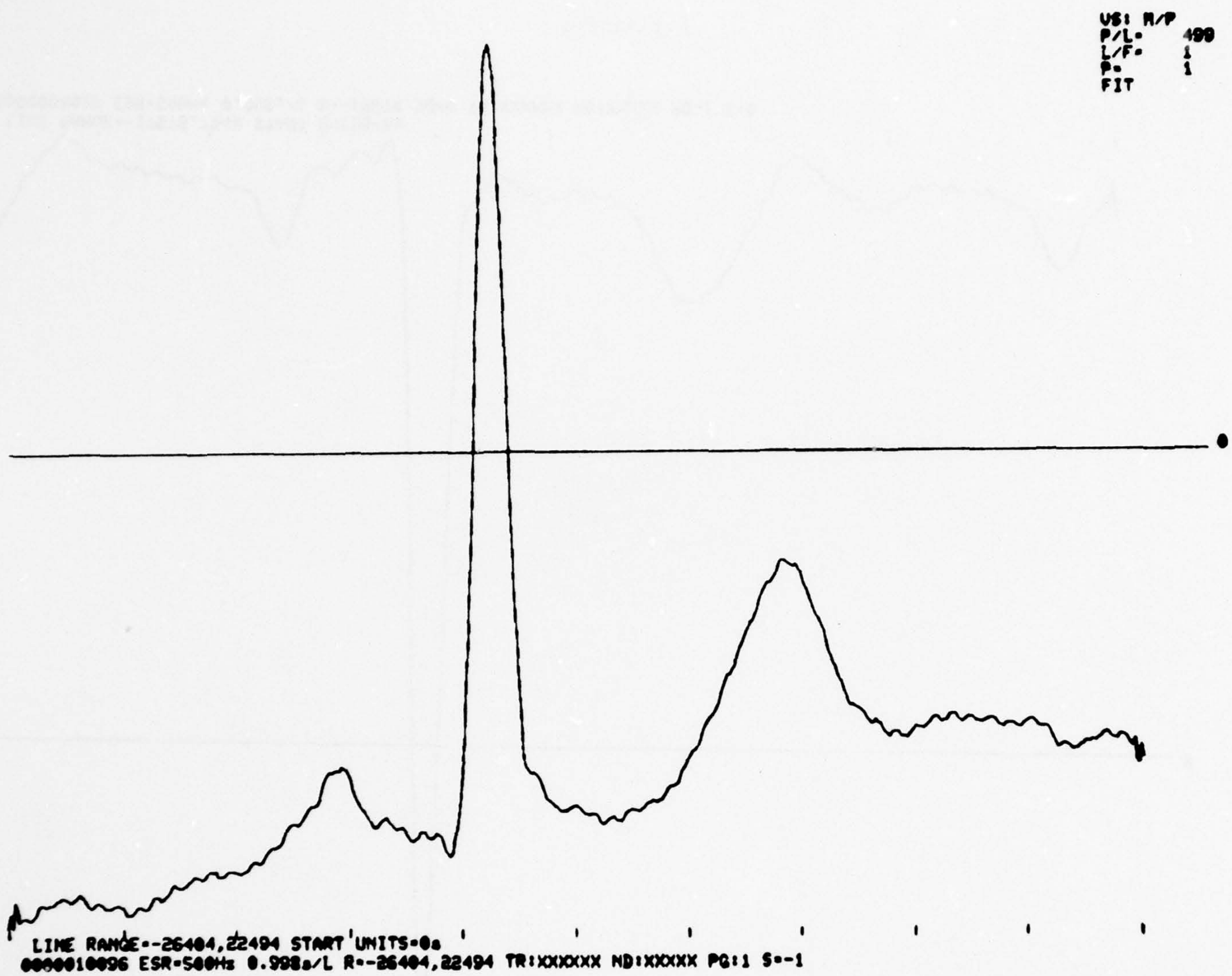

VS: M/P
P/L= 490
L/F= 1
P= 1
FIT
LINE RANGE=-26404,22494 START UNITS=0s
0000010096 ESR=500Hz 0.998s/L R=-26404,22494 TR:XXXXXX ND:XXXXX PG:1 S=-1

Figure F-6

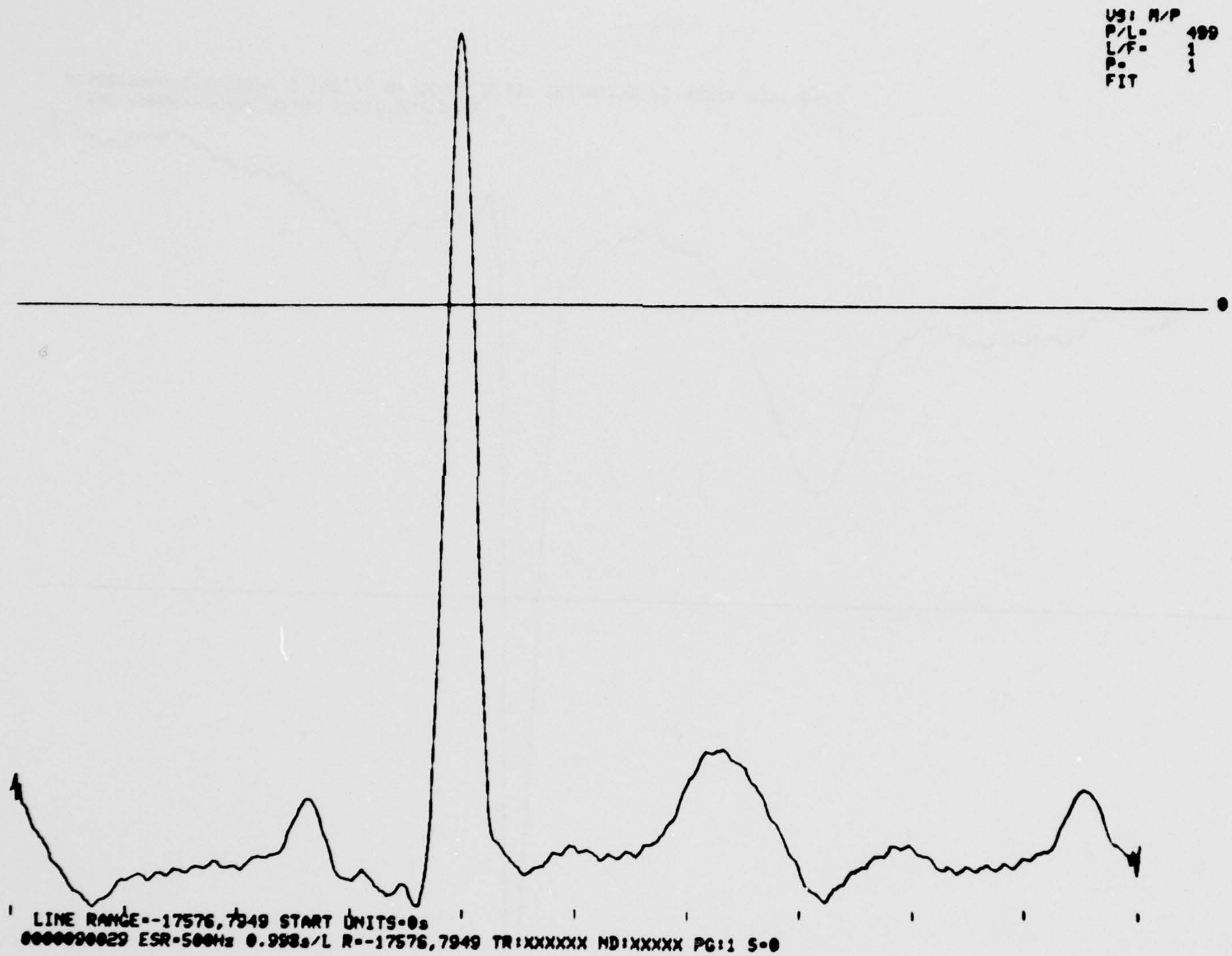

VS: M/P
P/L= 499
L/F= 1
P= 1
FIT
LINE RANGE=-17576,7949 START UNITS=0s
0000090029 ESR=500Hz 0.998s/L R=-17576,7949 TR:XXXXXX ND:XXXXX PG:1 S=0

Figure F-7

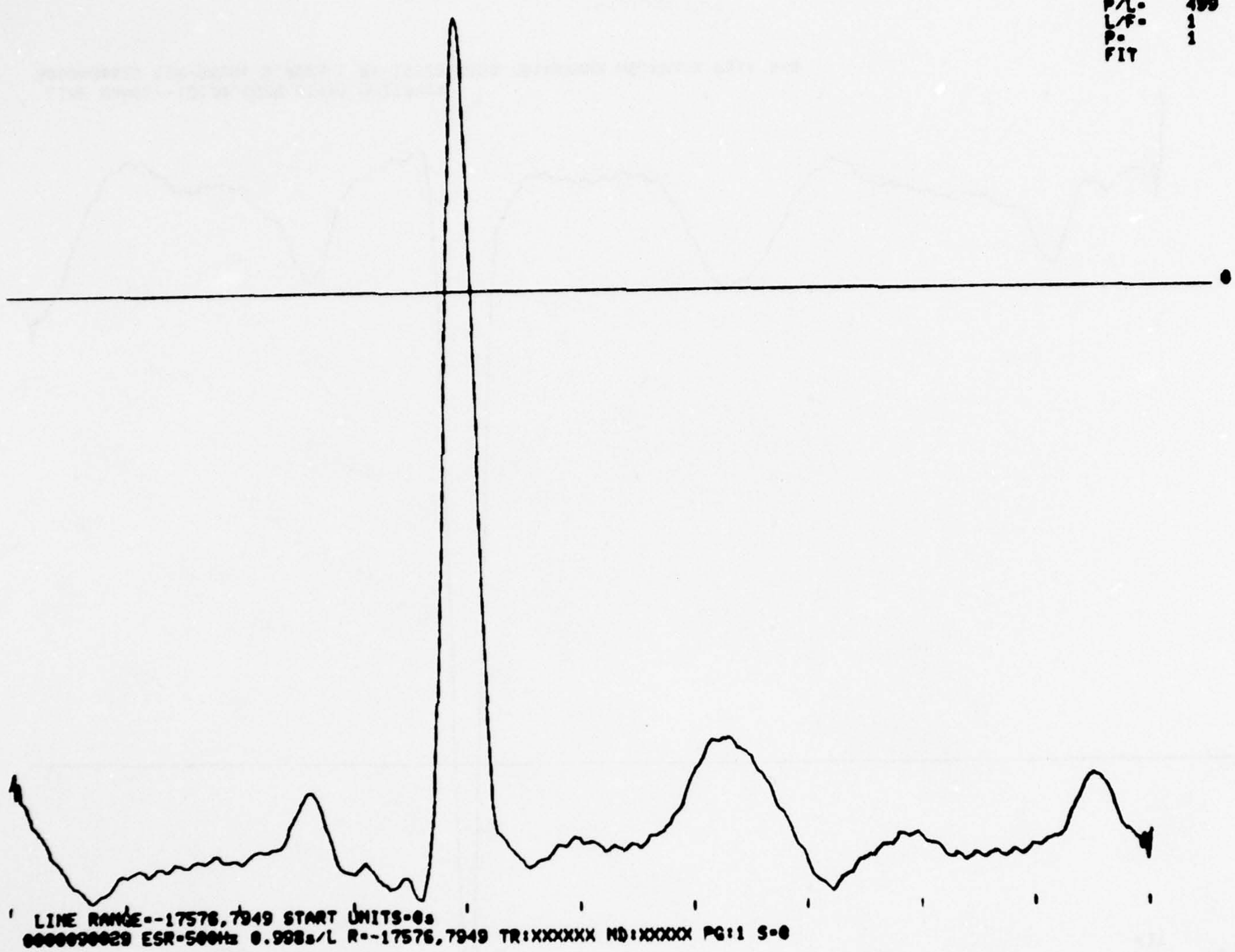

VS: M/P
P/L= 499
L/F= 1
P= 1
FIT
LINE RANGE=-17576,7949 START UNITS=0s
0000090029 ESR=500Hz 0.998s/L R=-17576,7949 TR:XXXXXX MD:XXXXX PG:1 S=0

Figure F-8

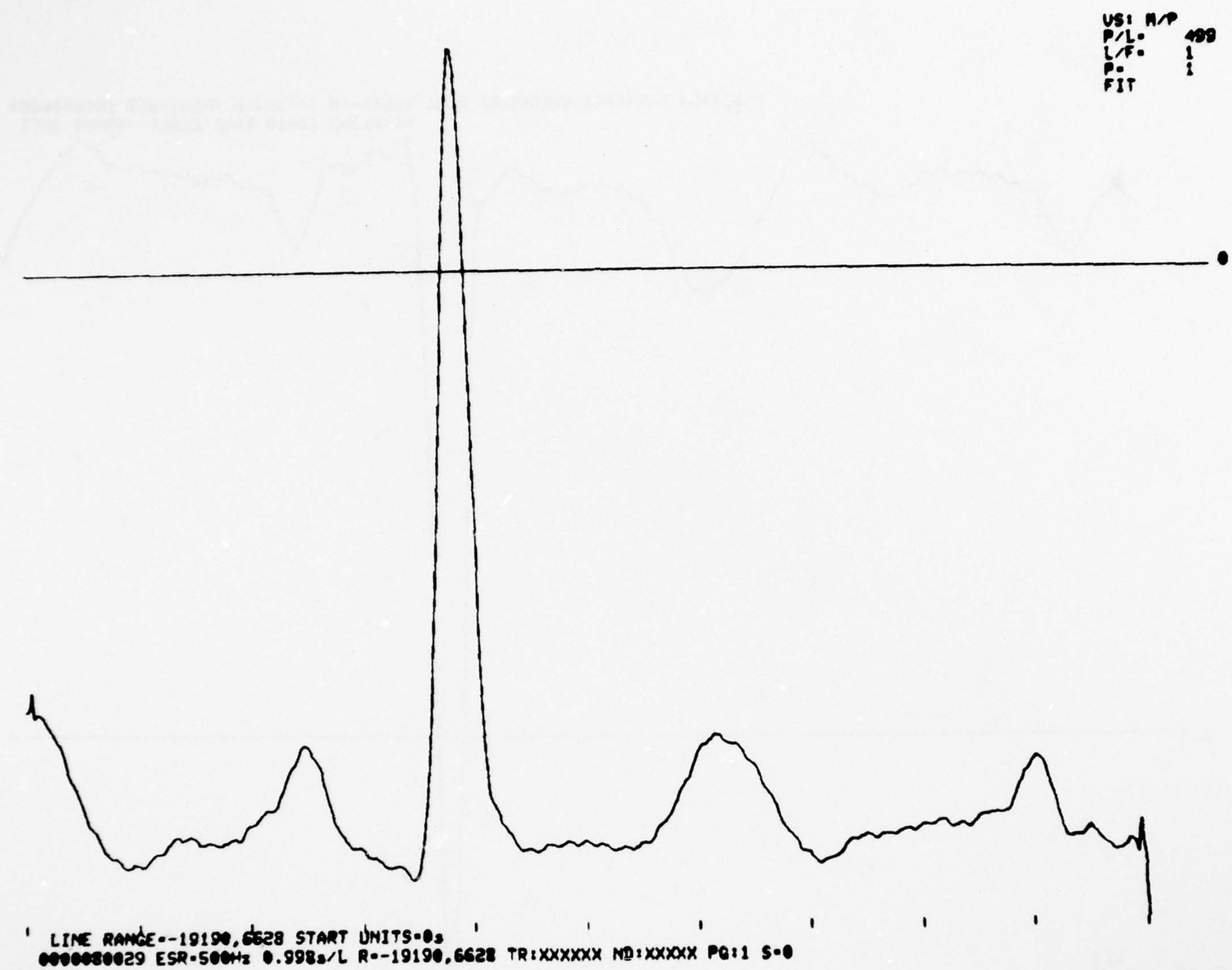
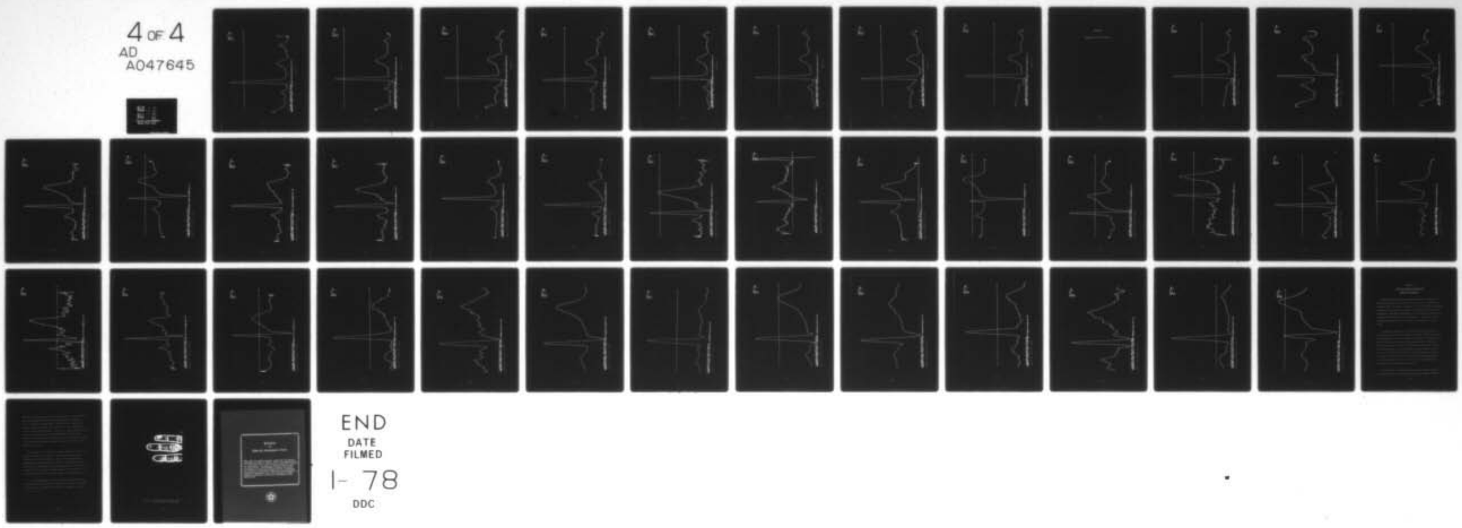

US: M/P
P/L= 499
L/F= 1
P= 1
FIT
LINE RANGE=-19190,6628 START UNITS=0s
0000080029 ESR=500Hz 0.998s/L R=-19190,6628 TR:XXXXXX ND:XXXXX PG:1 S=0

Figure F-9

AD-A047 645 PATTERN ANALYSIS AND RECOGNITION CORP ROME N Y F/G 6/4
PERSONAL ATTRIBUTES AUTHENTICATION TECHNIQUES.(U)
OCT 77 G E FORSEN, M R NELSON, R J STARON F30602-76-C-0368
UNCLASSIFIED PAR-77-21 RADC-TR-77-333 NL

4 OF 4
AD
A047645



END
DATE
FILMED
1-78
DDC

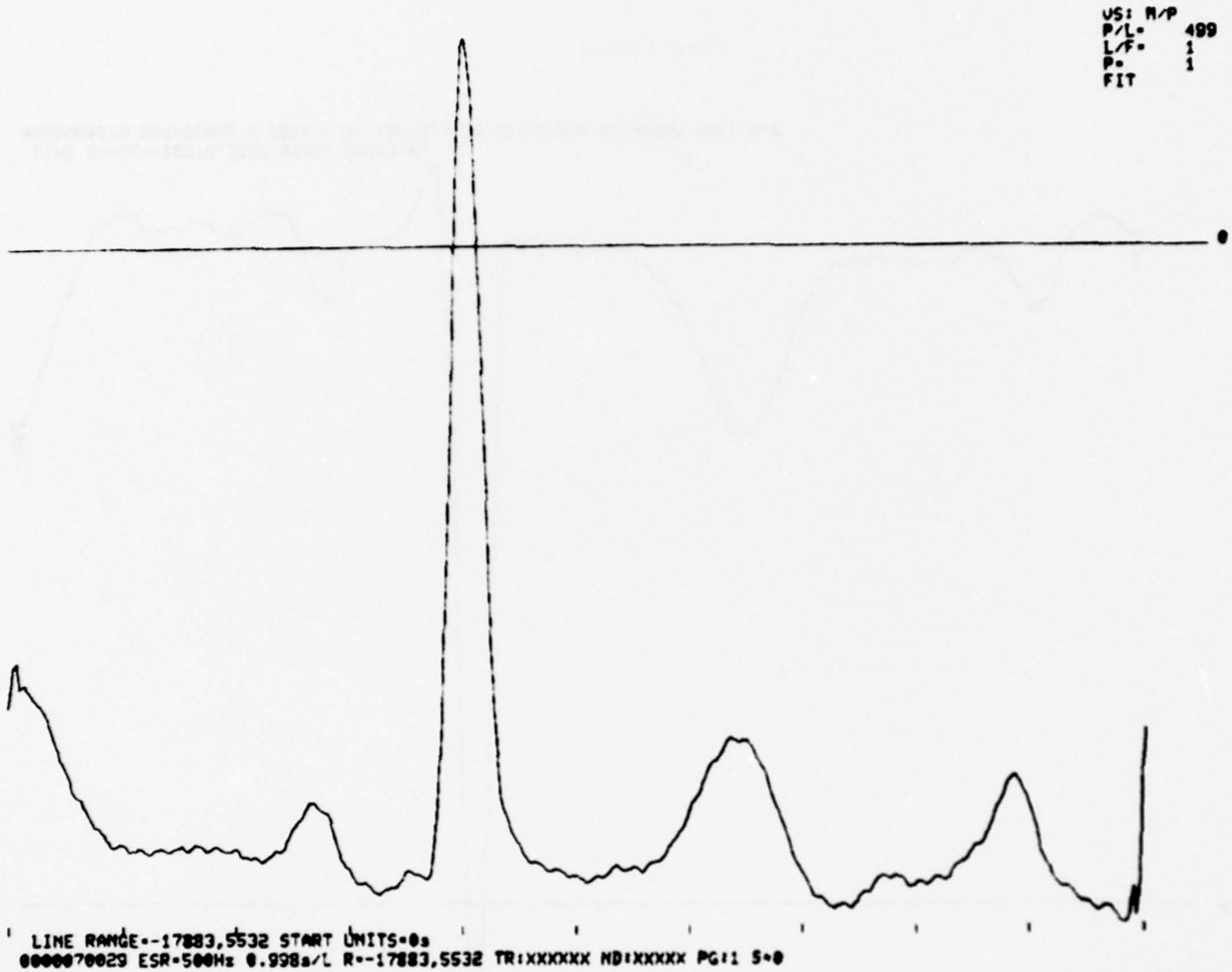

VS: M/P
P/L= 499
L/F= 1
P= 1
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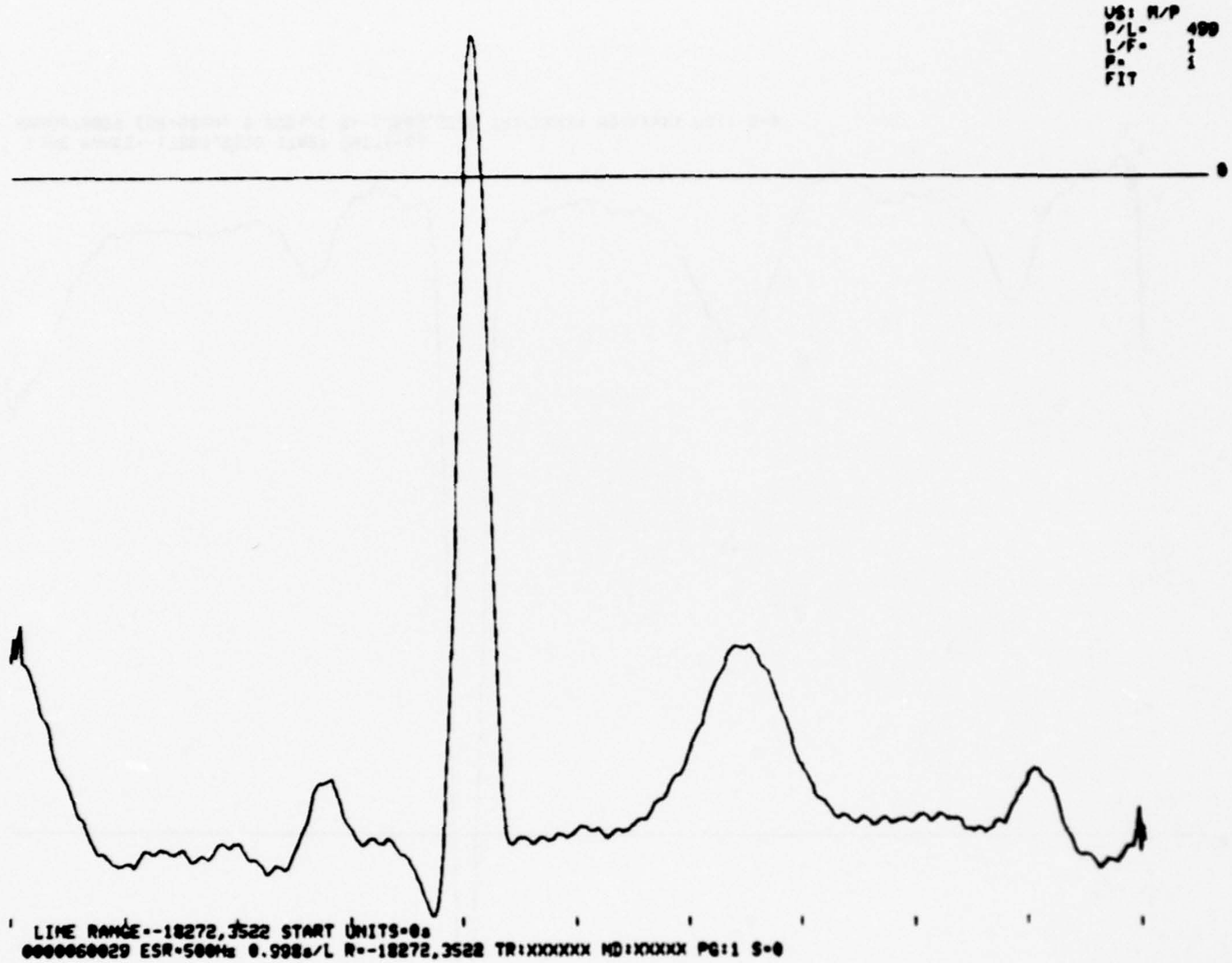
Figure F-10



VS: R/P
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L/F= 1
P= 1
FIT
0
LINE RANGE=-18272,3522 START UNITS=0s
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Figure F-11

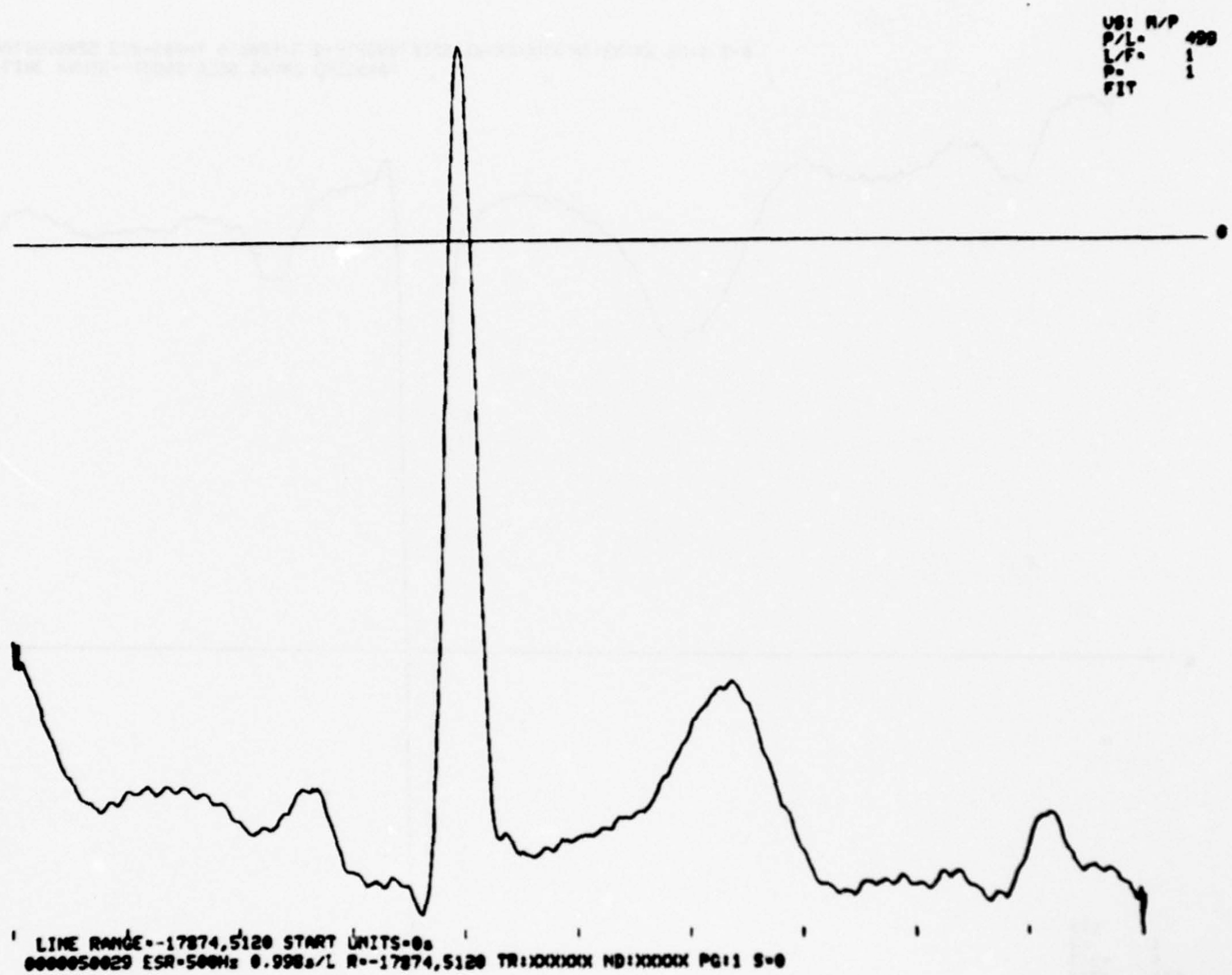
VS: R/P
P/L= 400
L/F= 1
P= 1
FIT
LINE RANGE=-17874,5120 START UNITS=0s
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Figure F-12

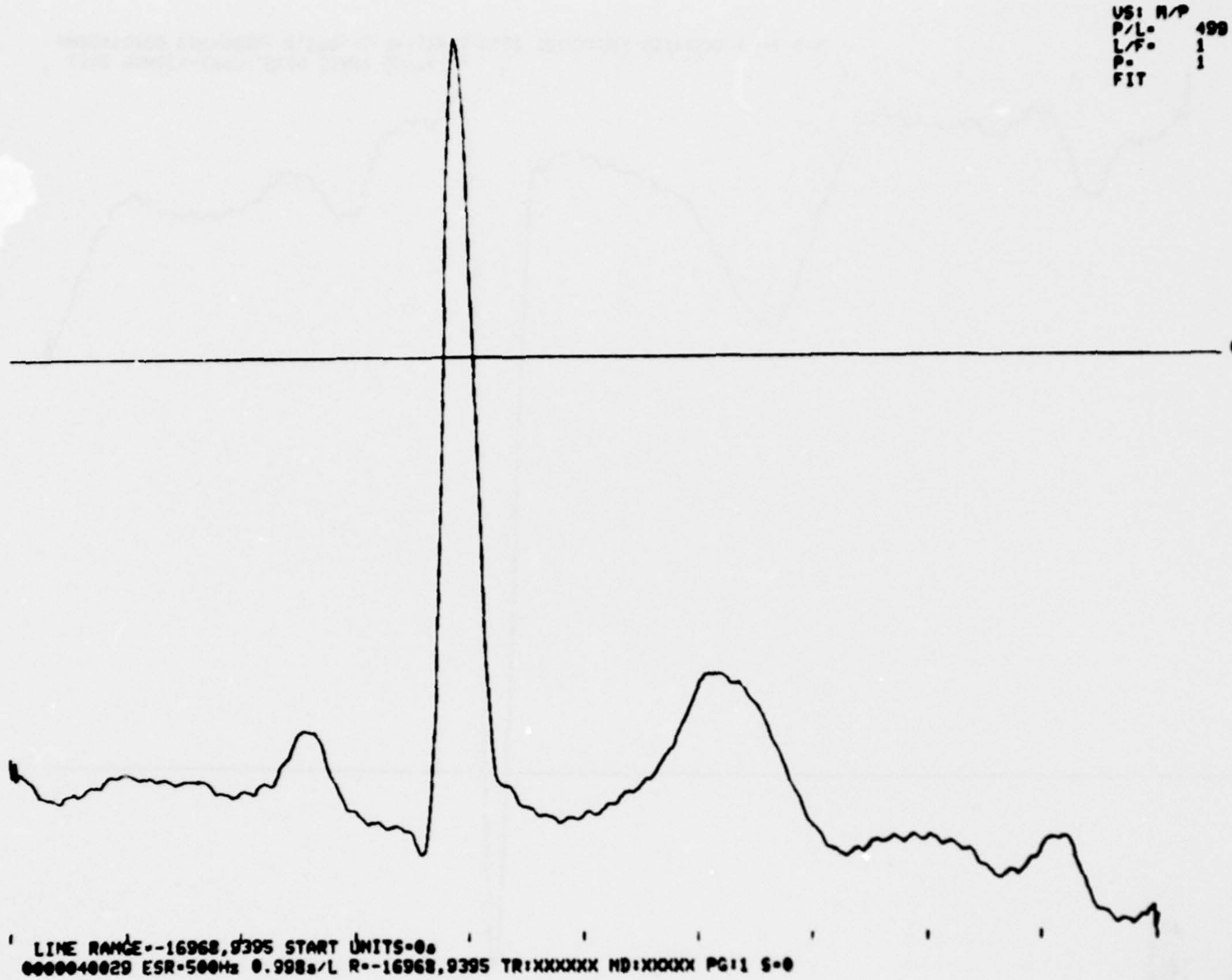
VS: M/P
P/L= 499
L/F= 1
P= 1
FIT
LINE RANGE=-16968,9395 START UNITS=0s
0000040029 ESR=500Hz 0.998s/L R=-16968,9395 TR:XXXXXX MD:XXXXX PG:1 S=0

Figure F-13

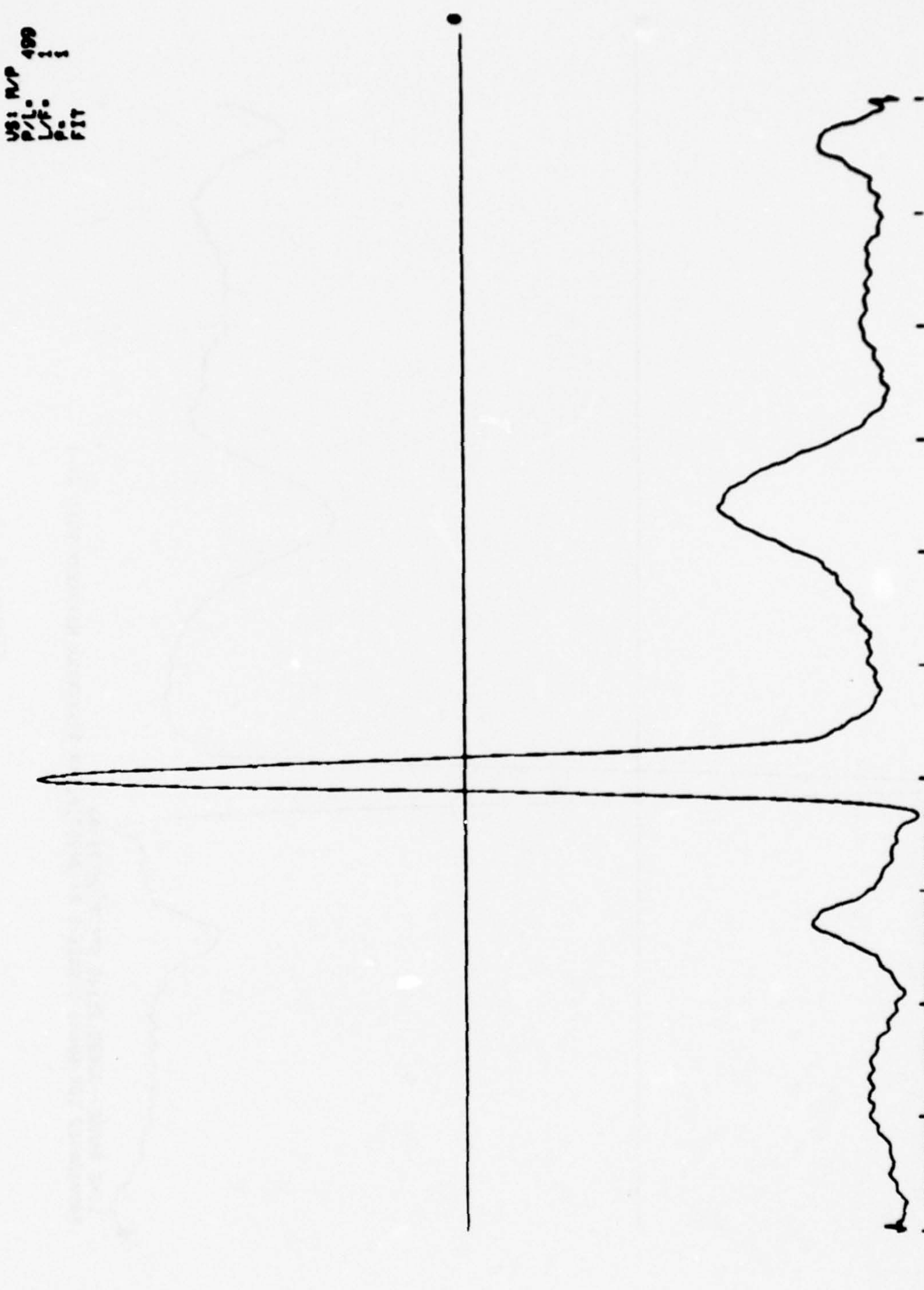
VS: R/P
FIT
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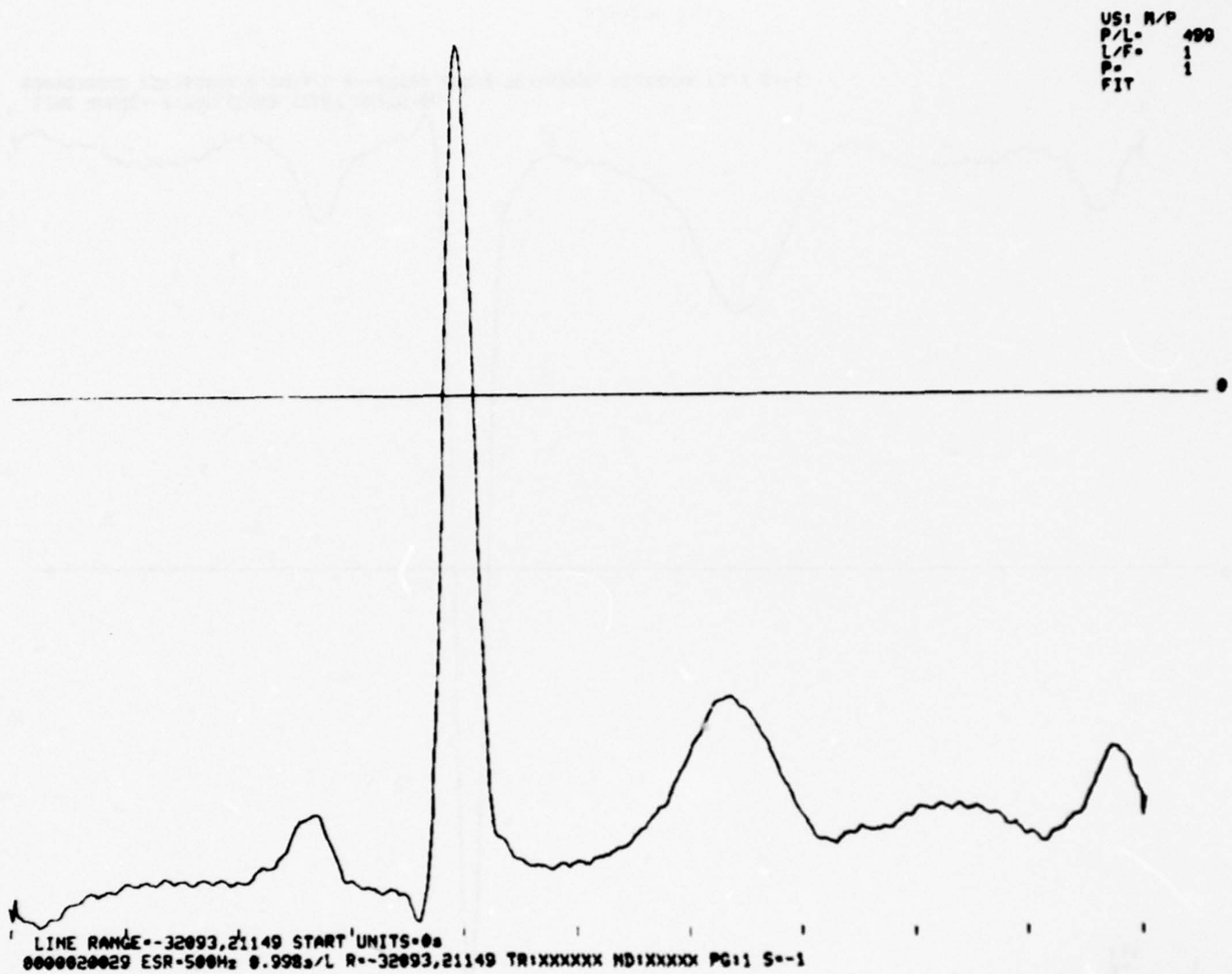
Figure F-14


US: R/P
P/L= 499
L/F= 1
P= 1
FIT
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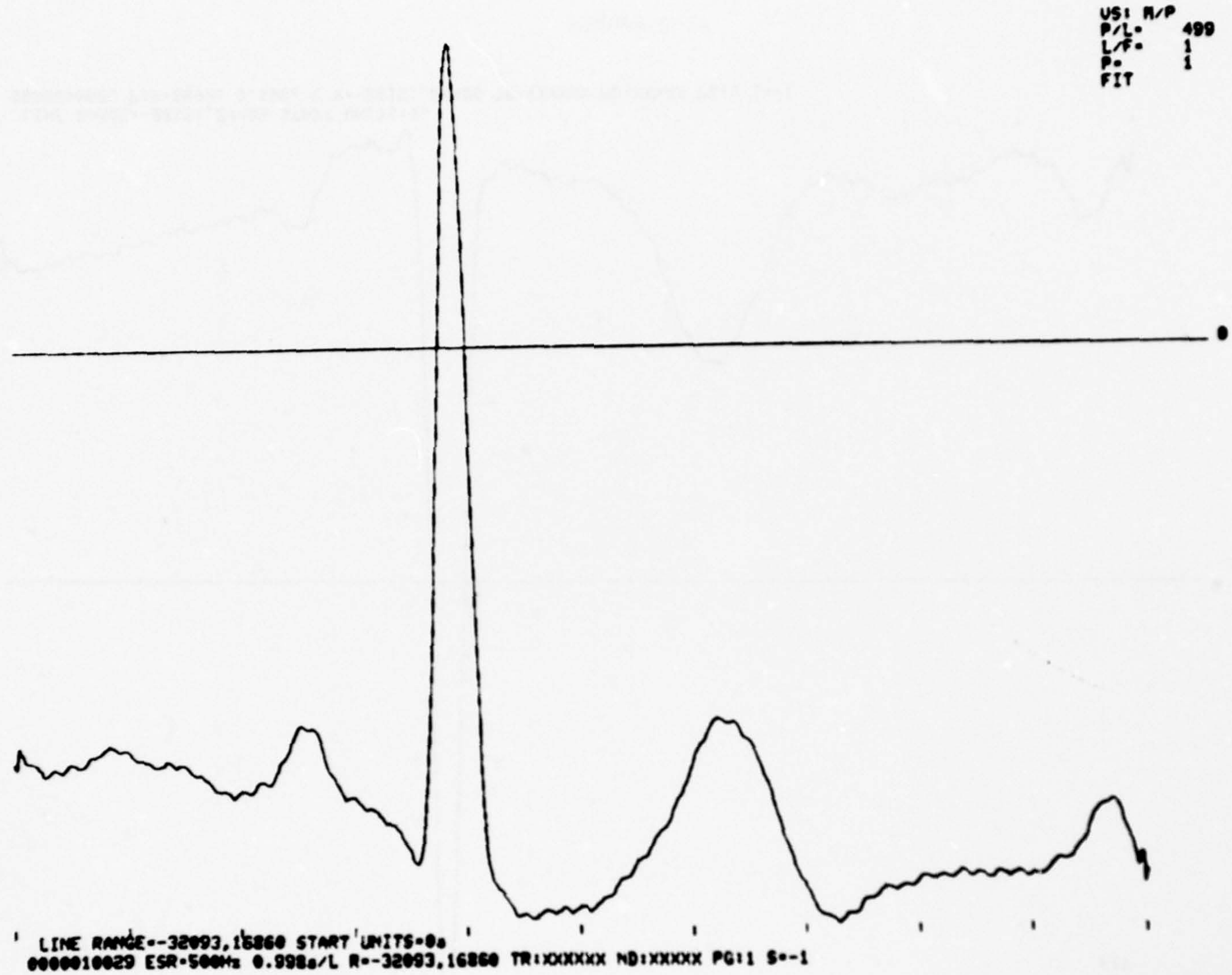
0000020029 ESR=500Hz 0.998s/L R=-32093,21149 TR:XXXXXX MD:XXXXX PG:1 S=-1

Figure F-15


US: M/P
P/L= 499
L/F= 1
P= 1
FIT
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0000010029 ESR=500Hz 0.998s/L R=-32093,16860 TR:XXXXXX ND:XXXXX PG:1 S=-1

Figure F-16

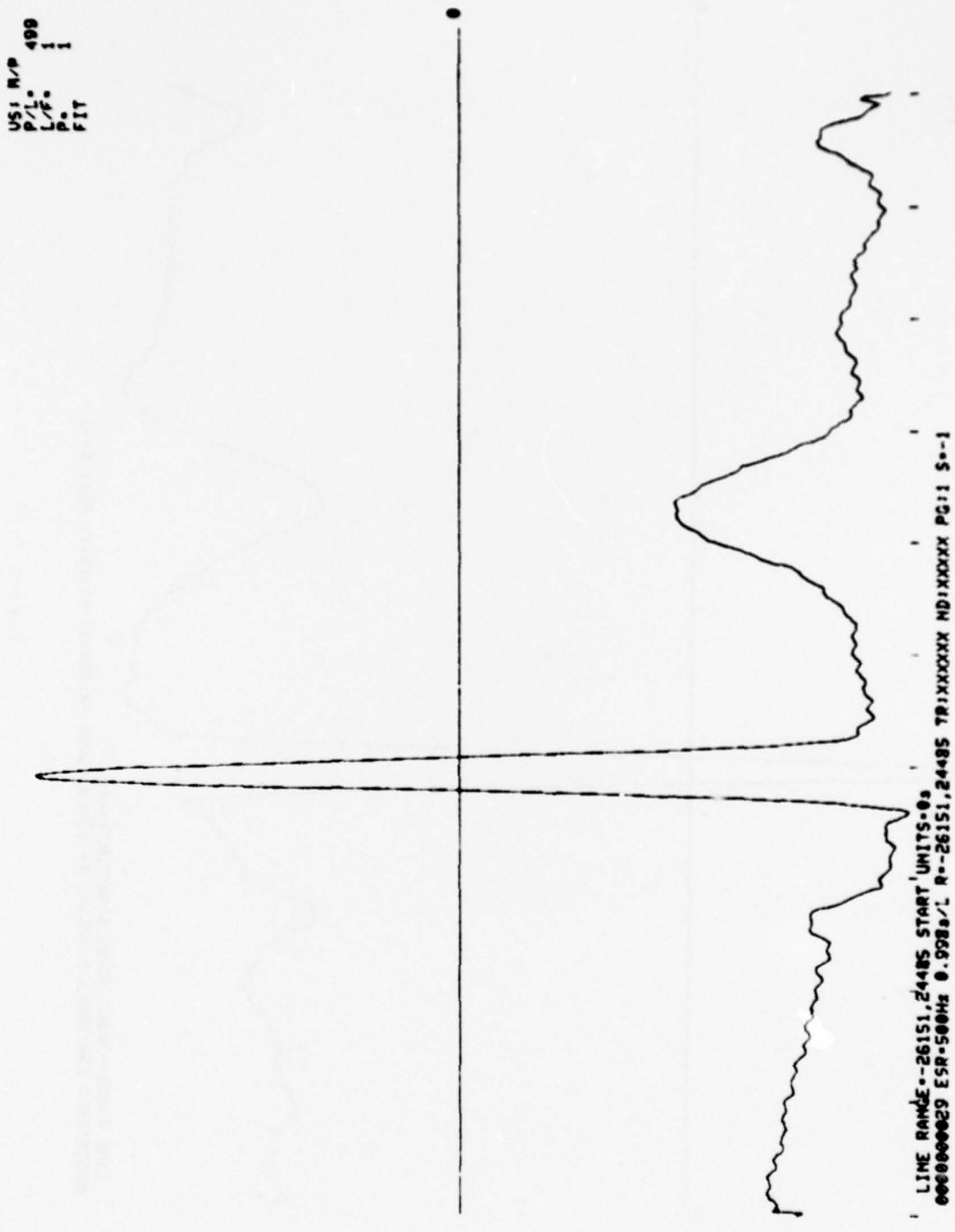
US: R/P
P/L: 499
L/F: 1
P: 1
FIT
LINE RANGE=-26151,24485 START UNITS=0s
0000000029 ESR=500Hz 0.998s/L R=-26151,24485 TR:XXXXXXX ND:XXXXX PG:1 S=-1

Figure F-17

APPENDIX G

Cardiograms of Thirty Subjects

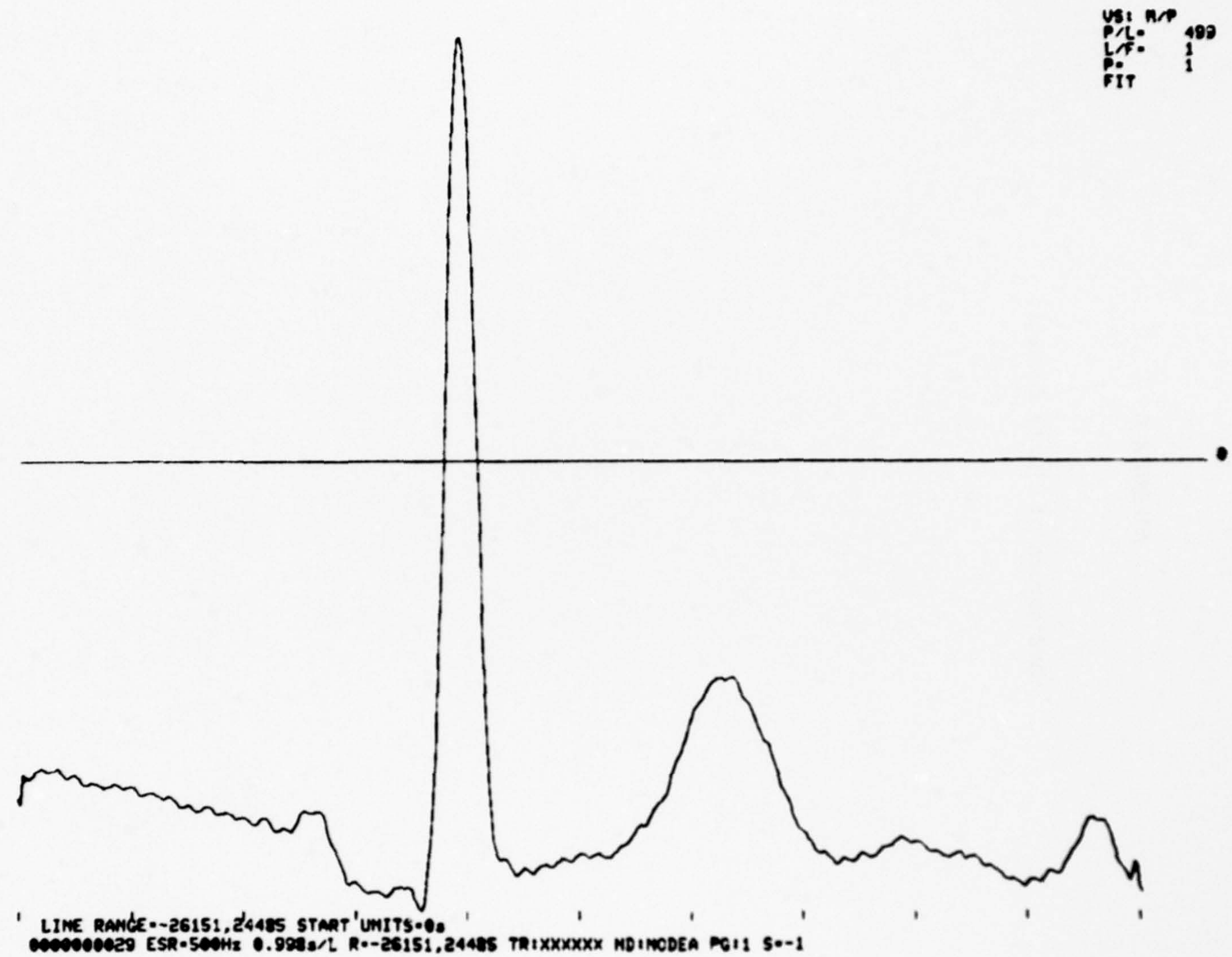

Figure G-1 Subject A C-trace.

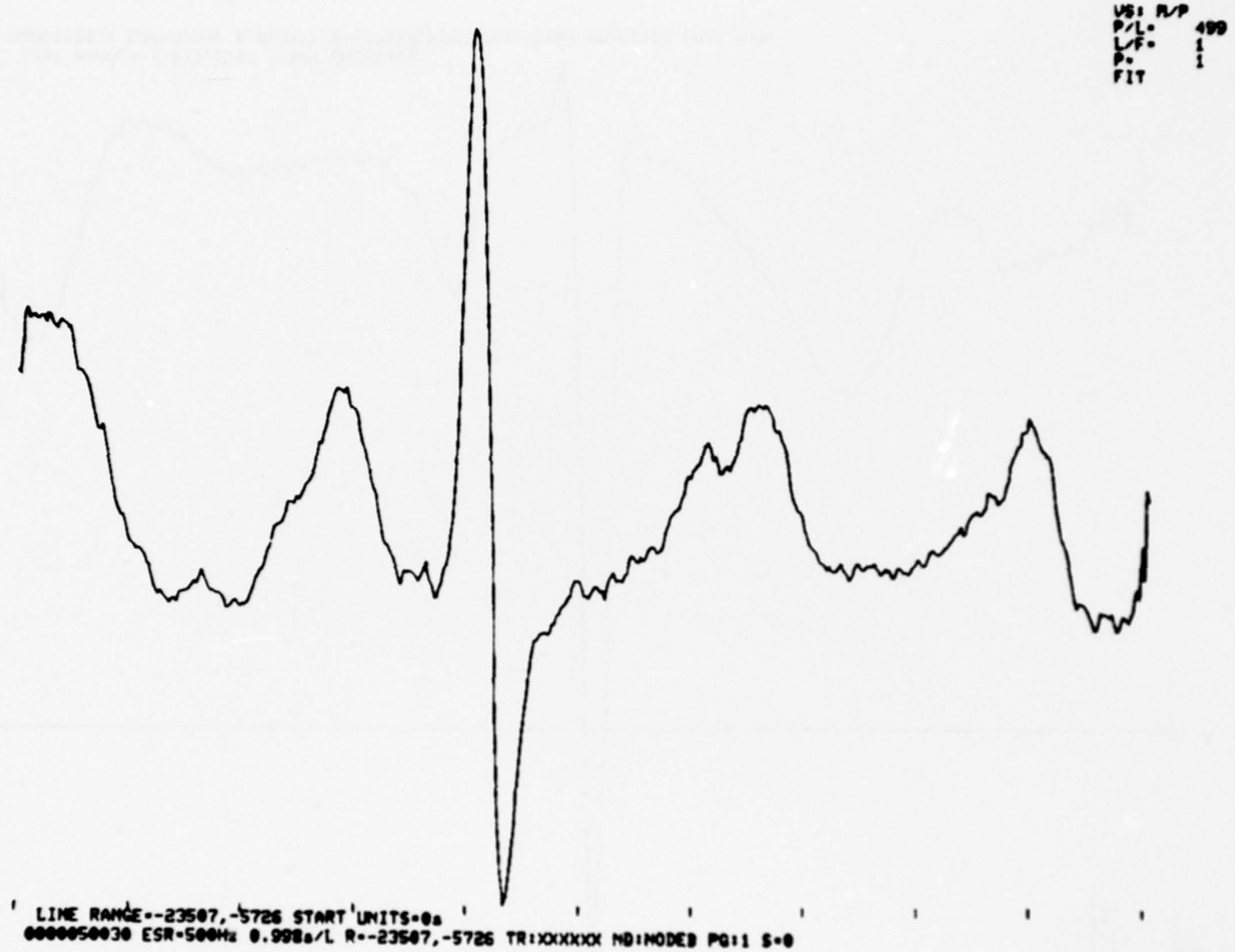

Figure G-2 Subject B C-trace

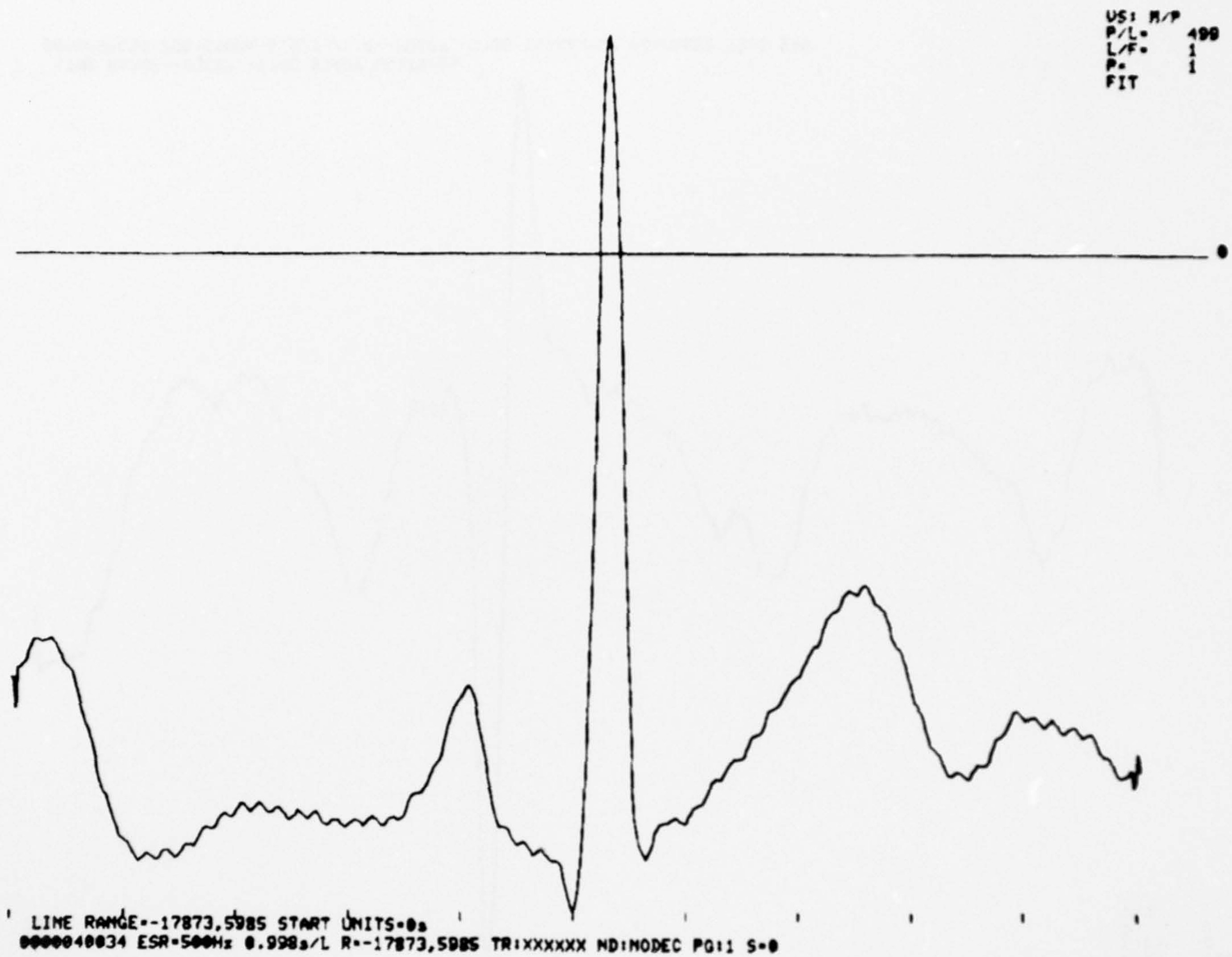

Figure G-3 Subject C C-trace.

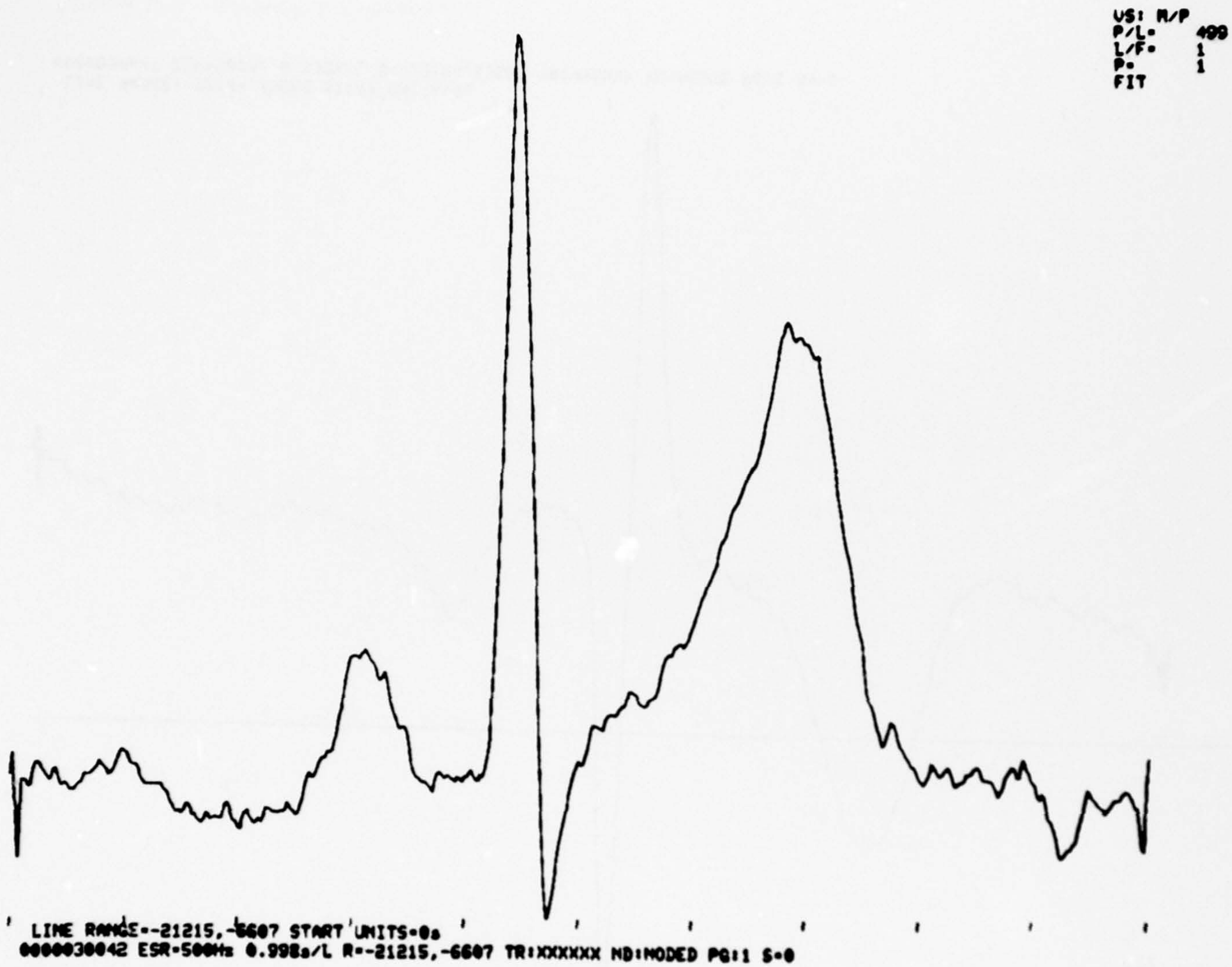

Figure G-4 Subject D C-trace.

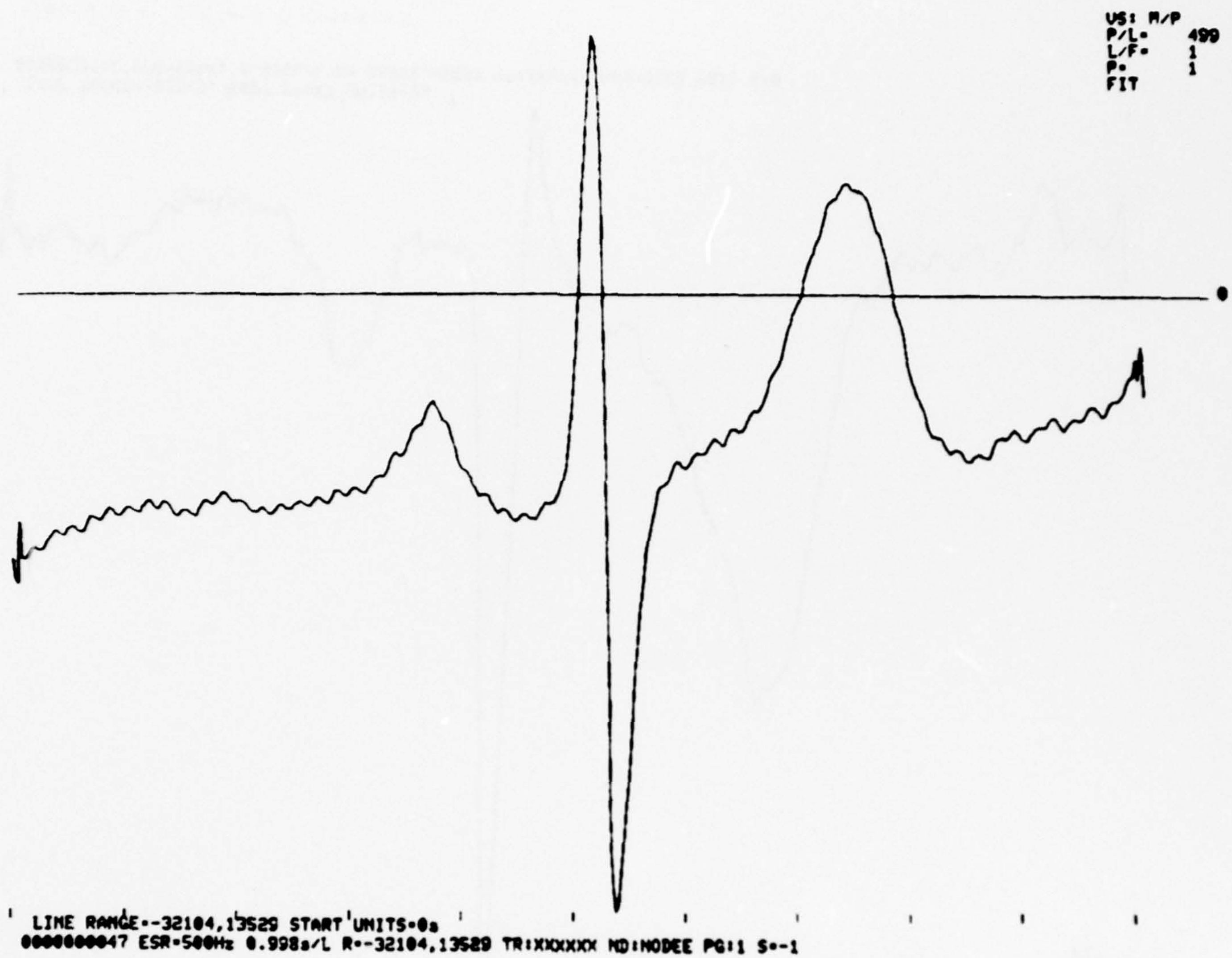

Figure G-5 Subject E C-trace.

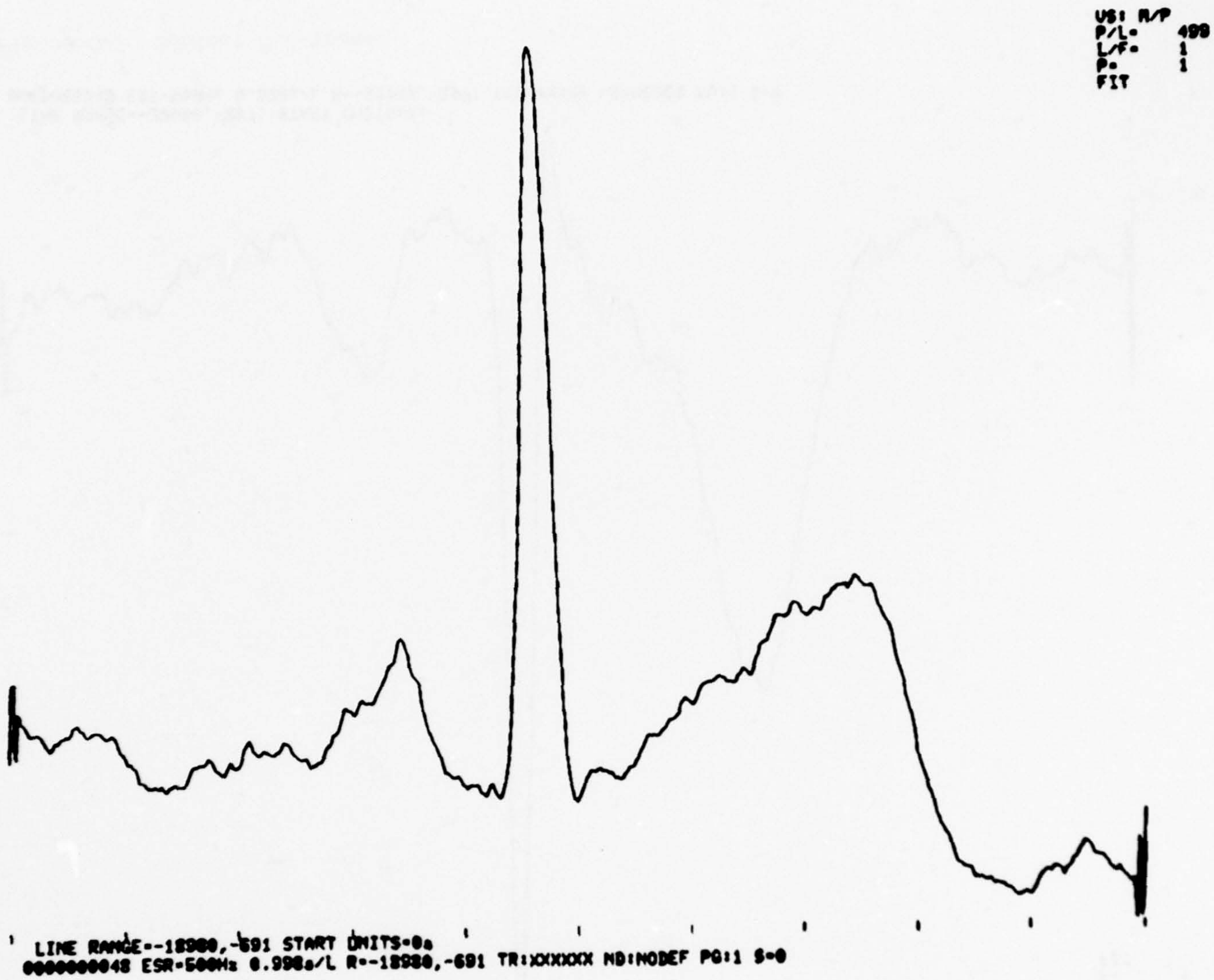

Figure G-6 Subject F C-trace.

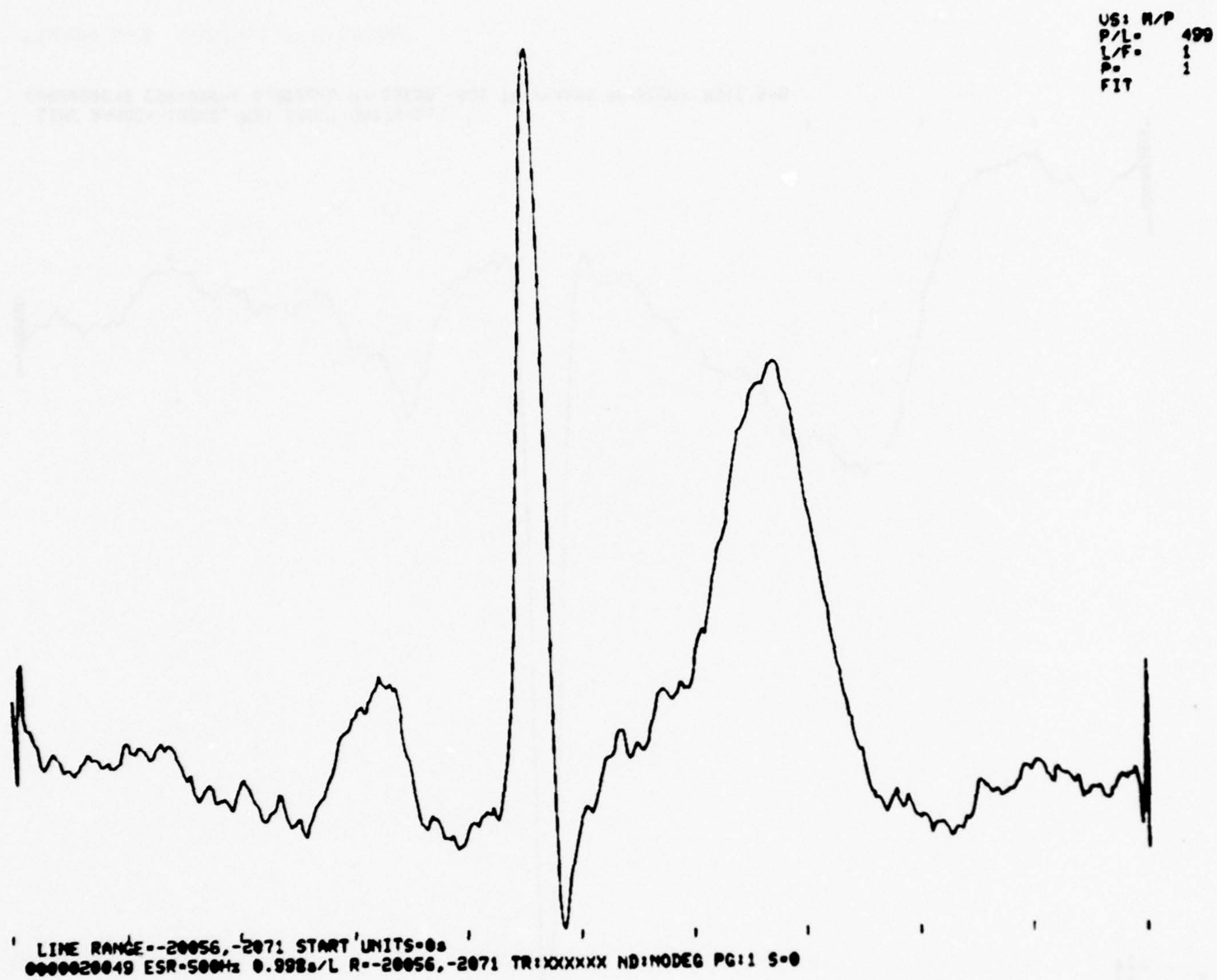

Figure G-7 Subject G C-trace.

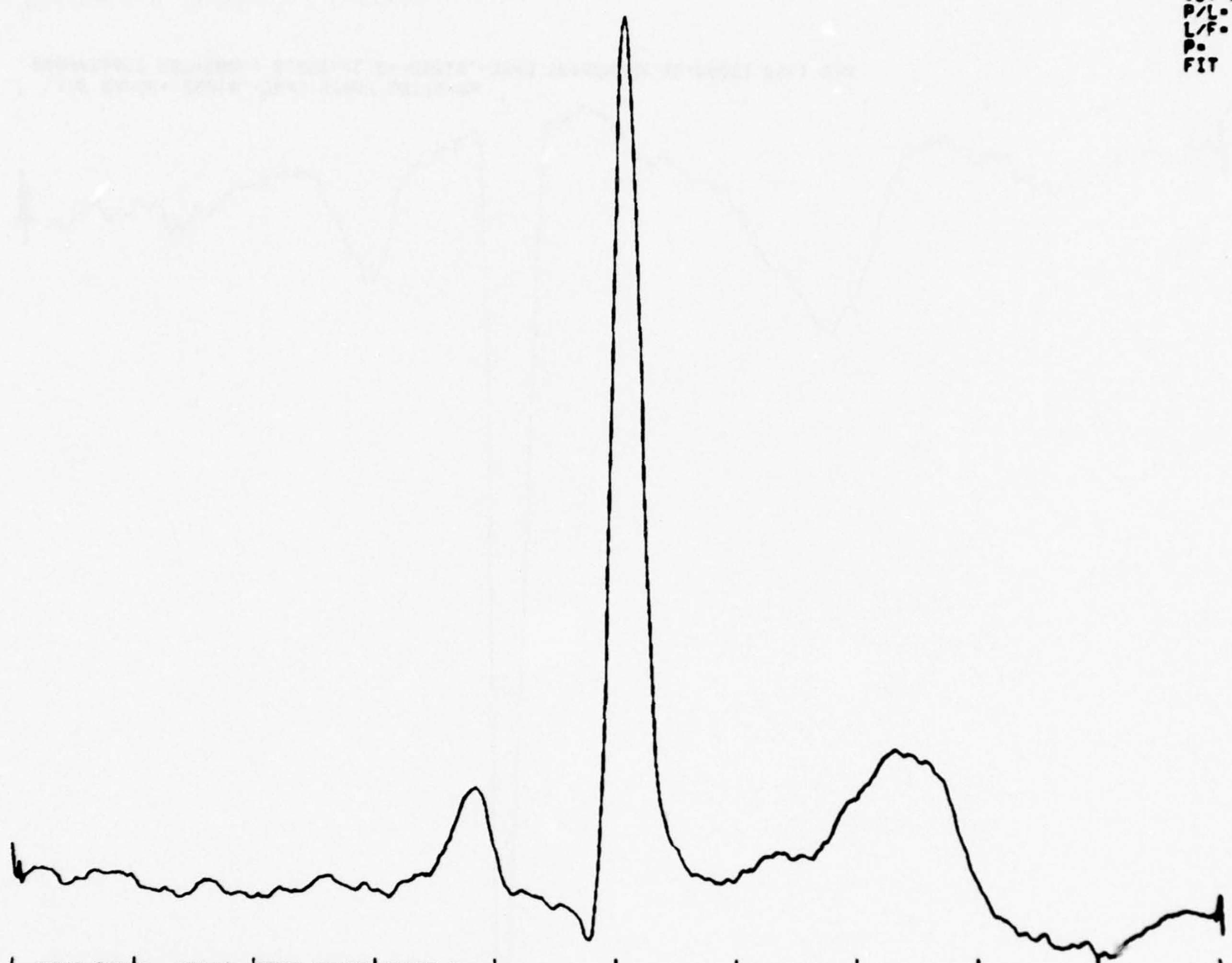

Figure G-8 Subject H C-trace.

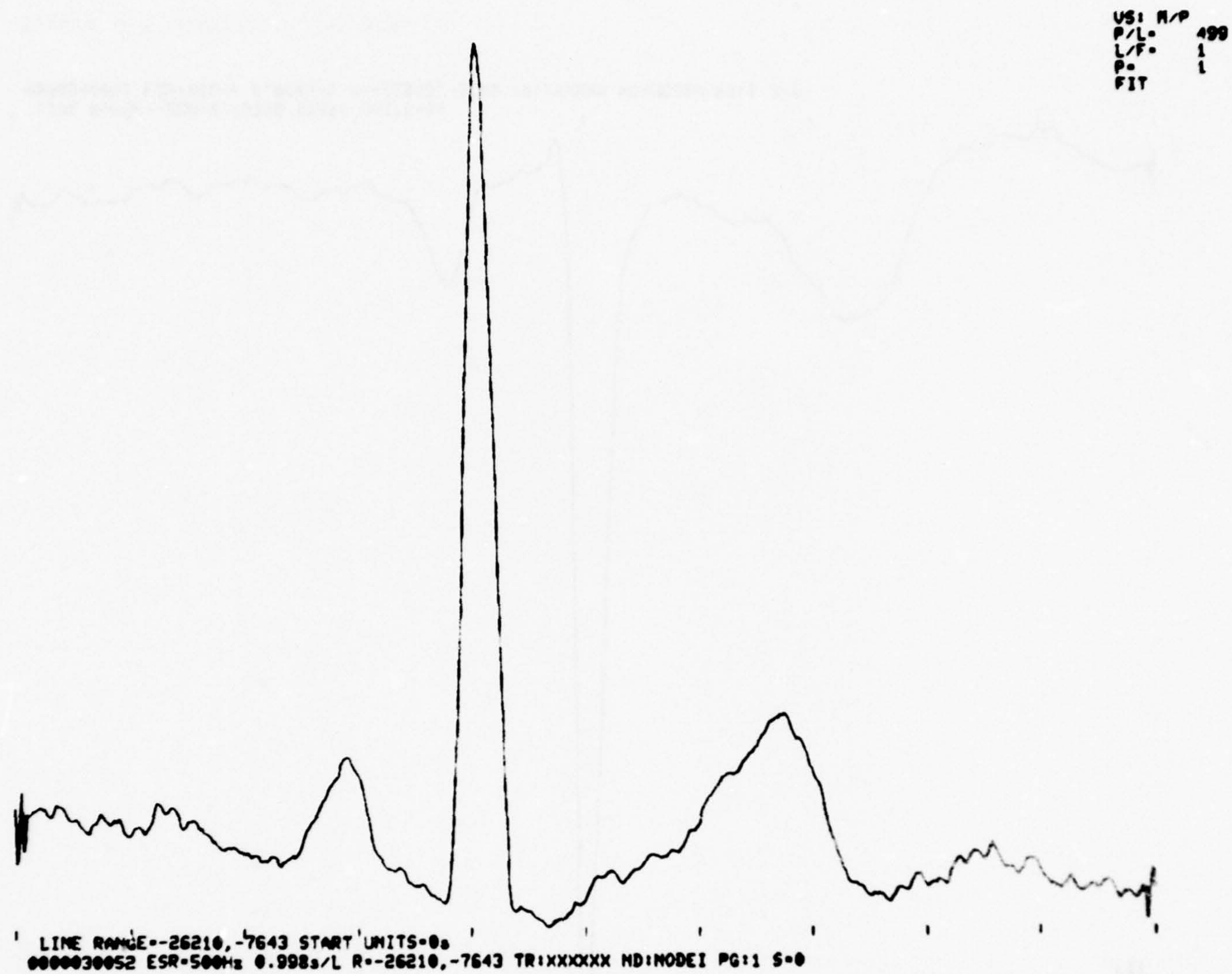

Figure G-9 Subject I C-trace.

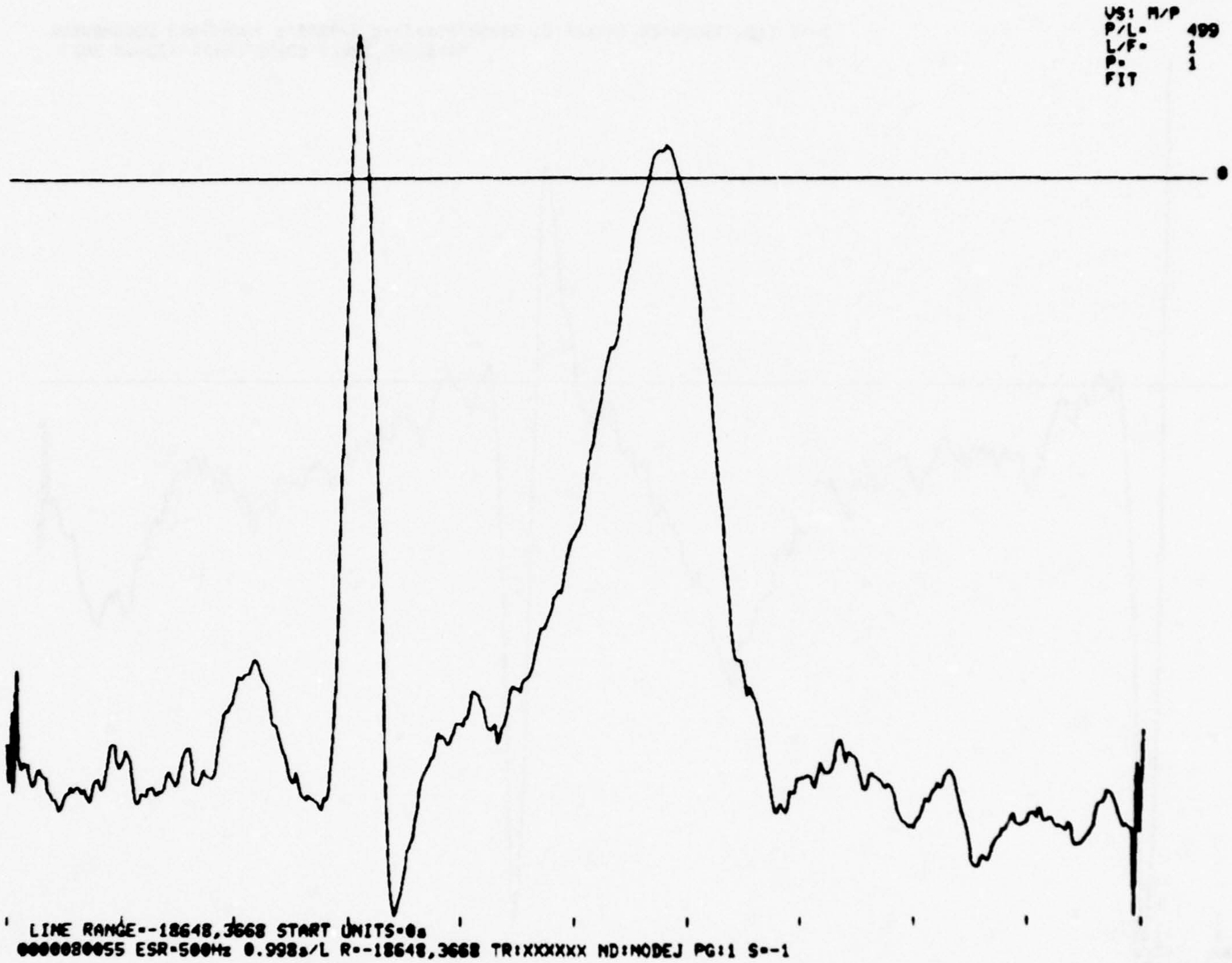

Figure G-10 Subject J C-trace.

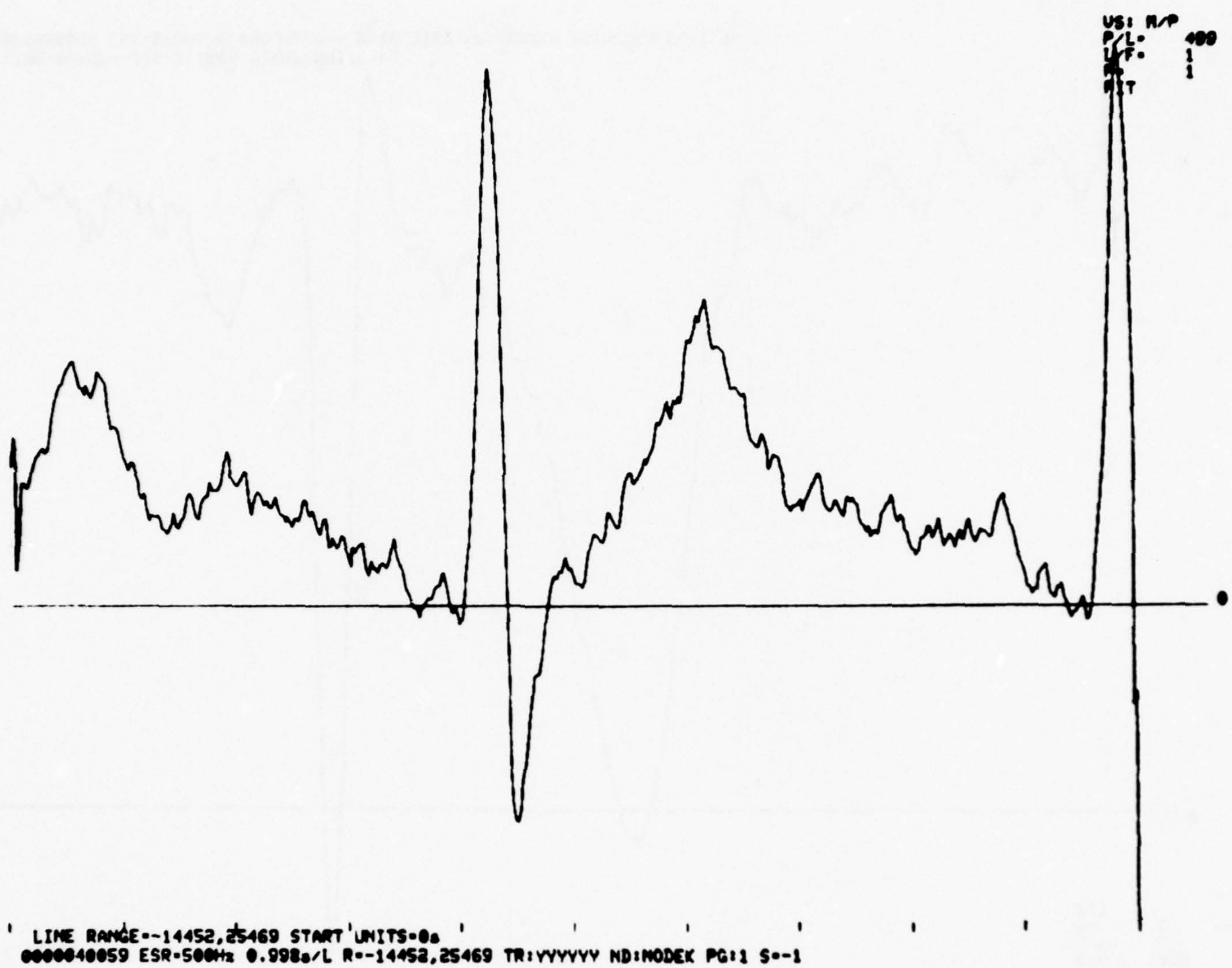

Figure G-11 Subject K C-trace.

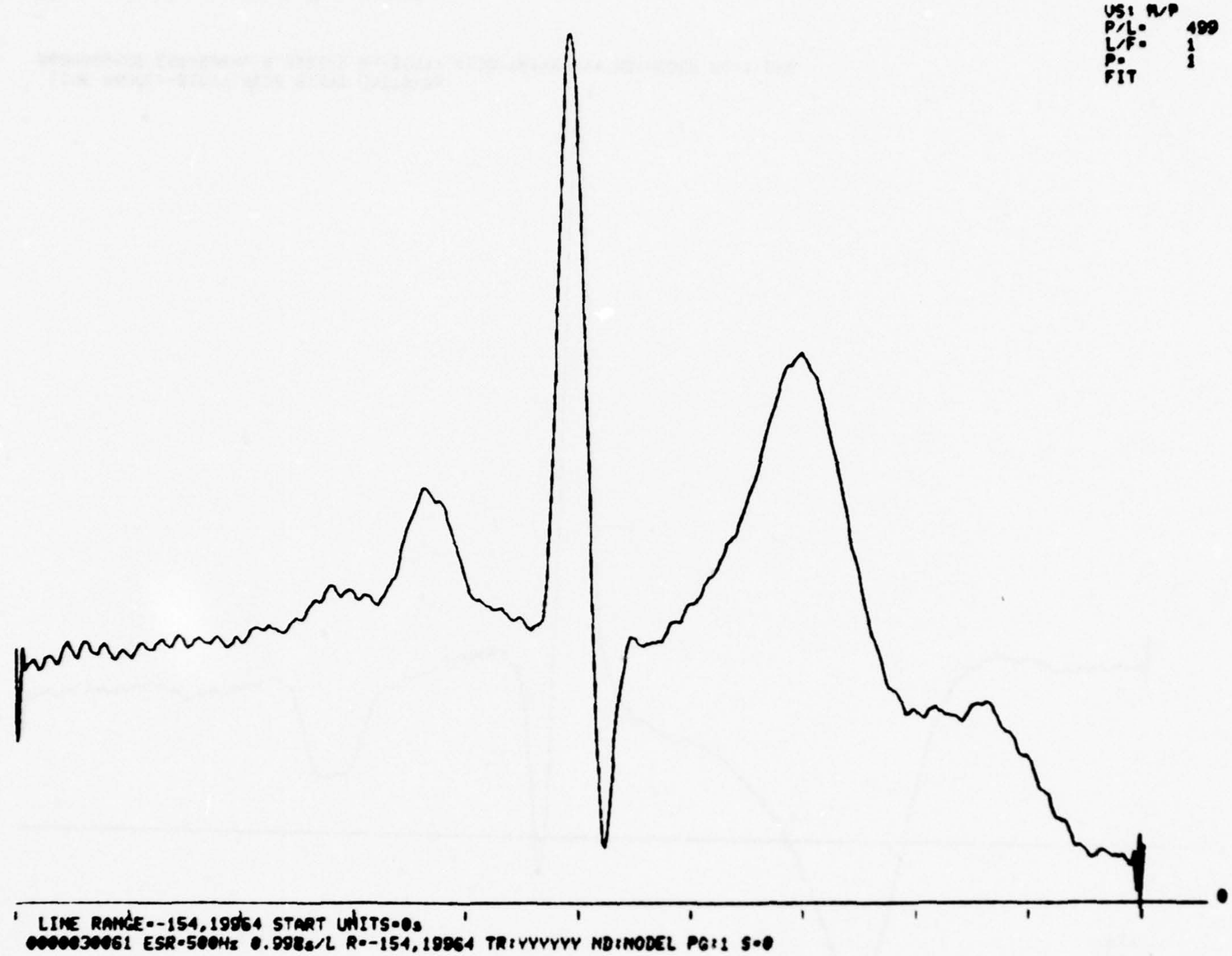

Figure G-12 Subject L C-trace.

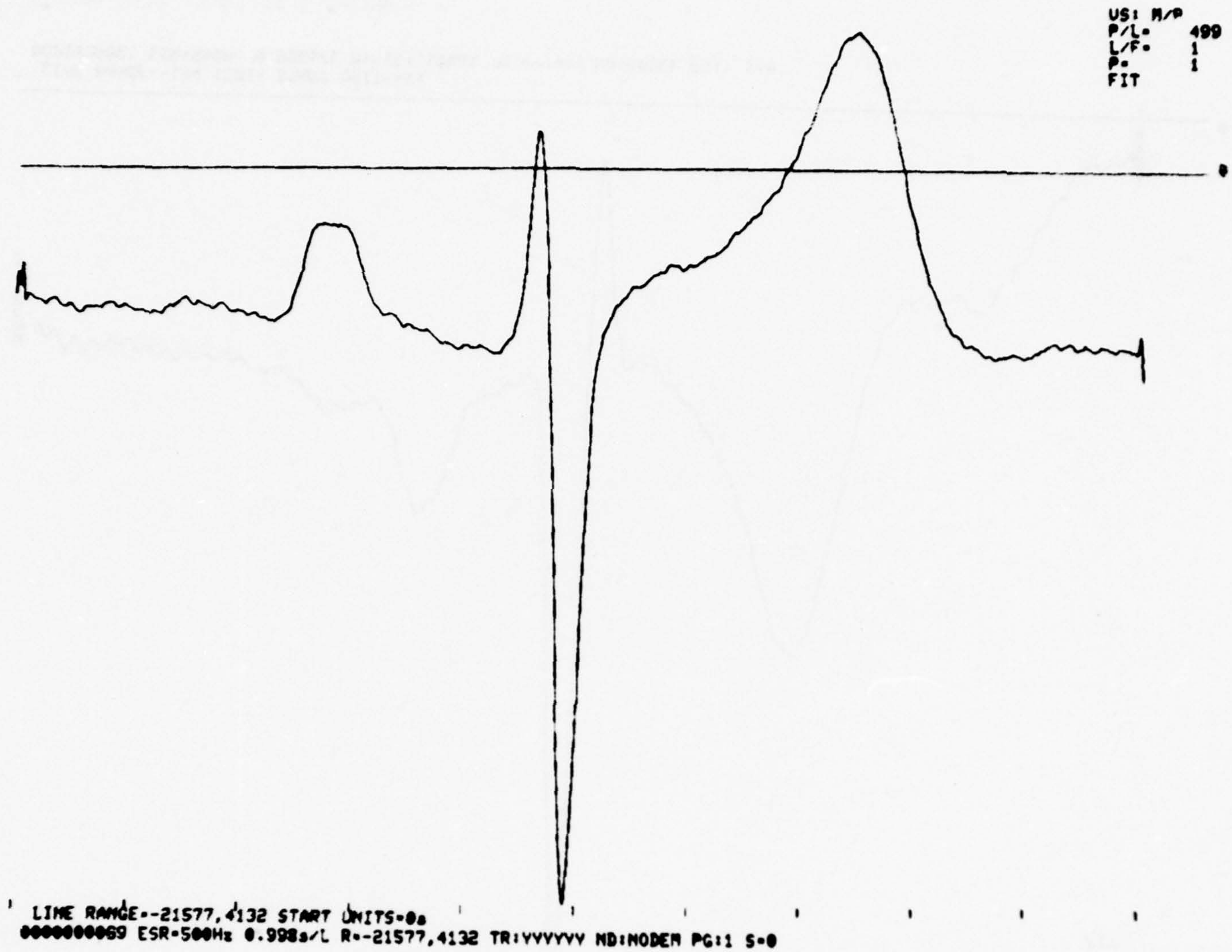

Figure G-13 Subject M C-trace.

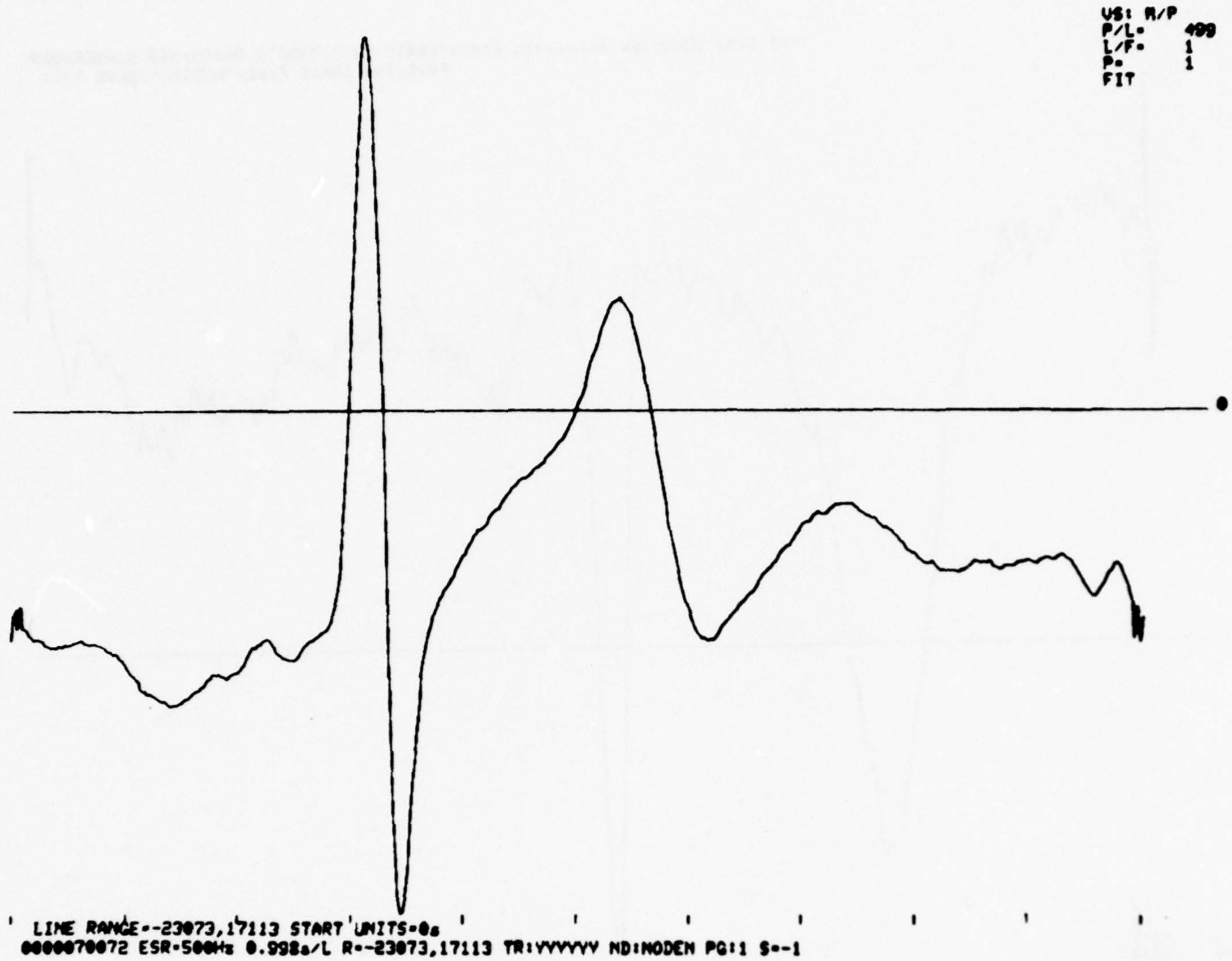

Figure G-14 Subject N C-trace.

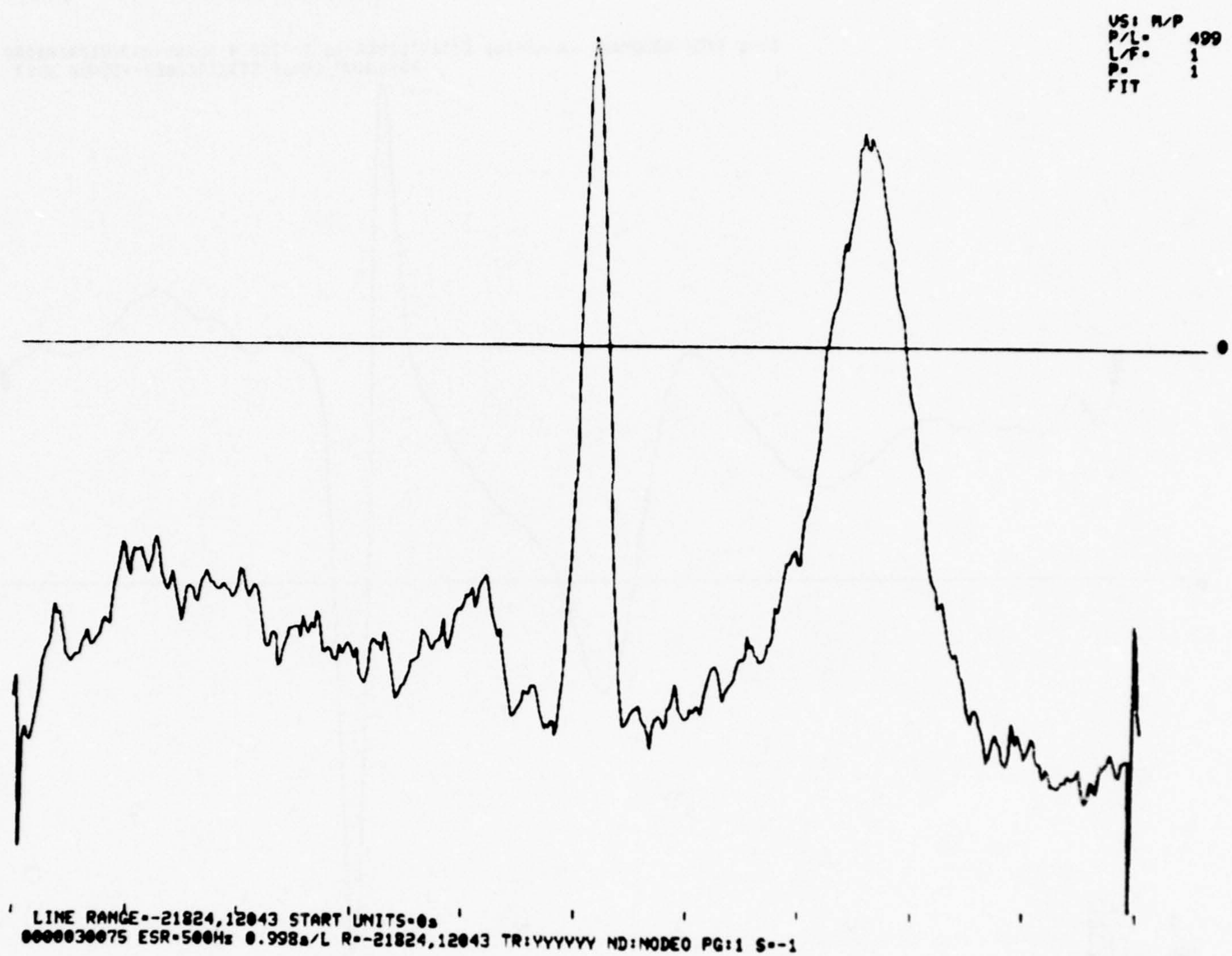

Figure G-15 Subject O C-trace.

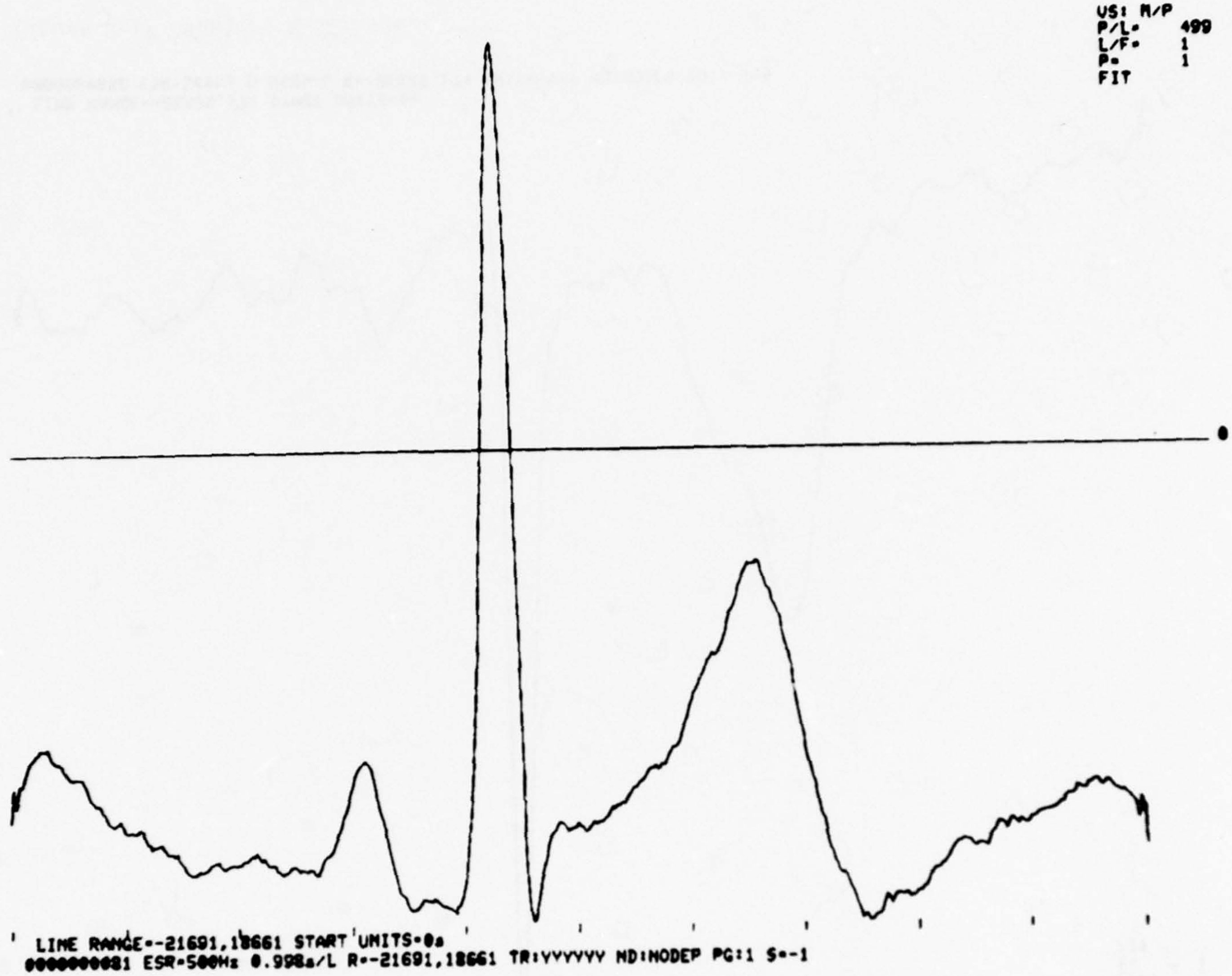

Figure C-16 Subject P C-trace.

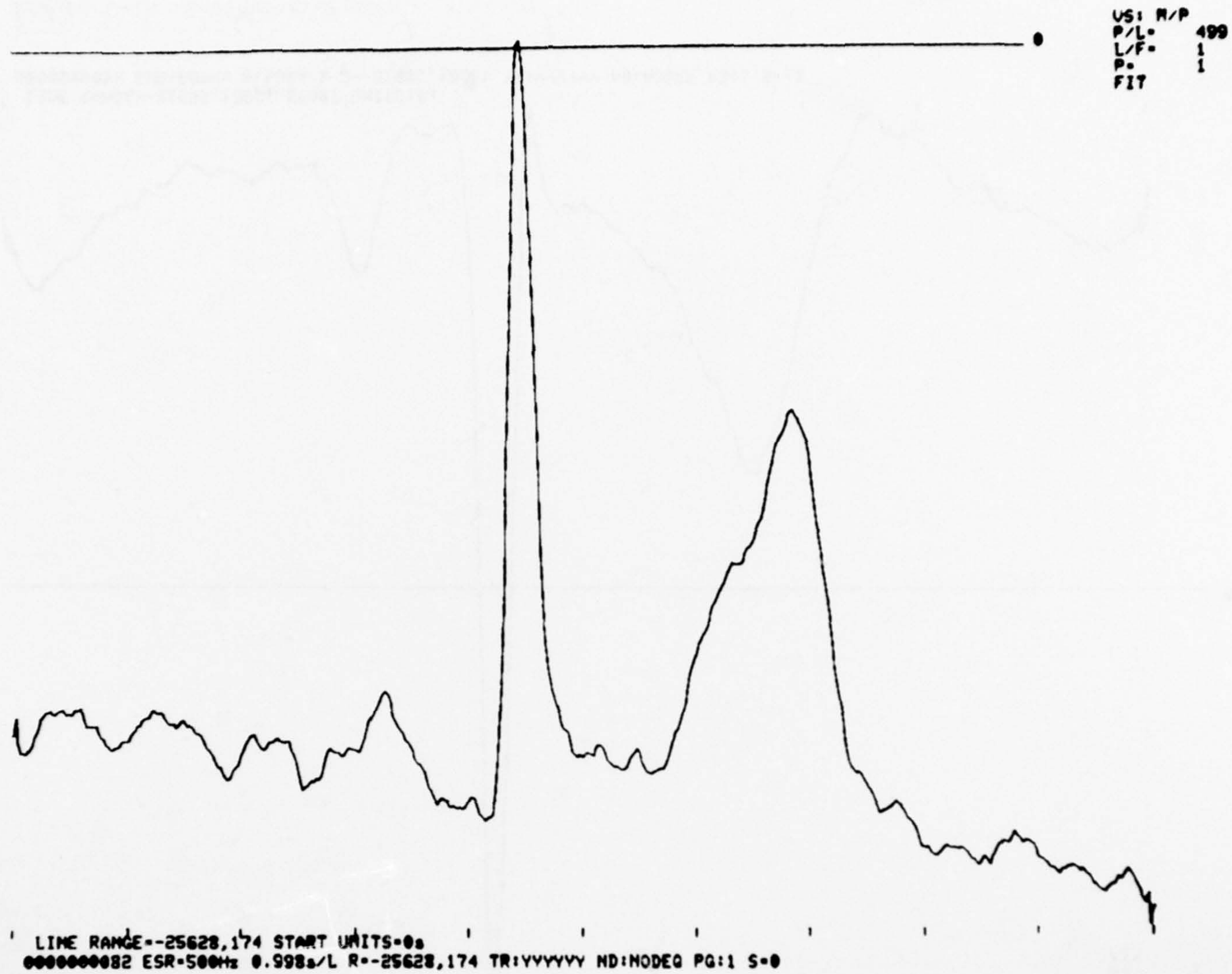

Figure G-17 Subject Q C-trace.

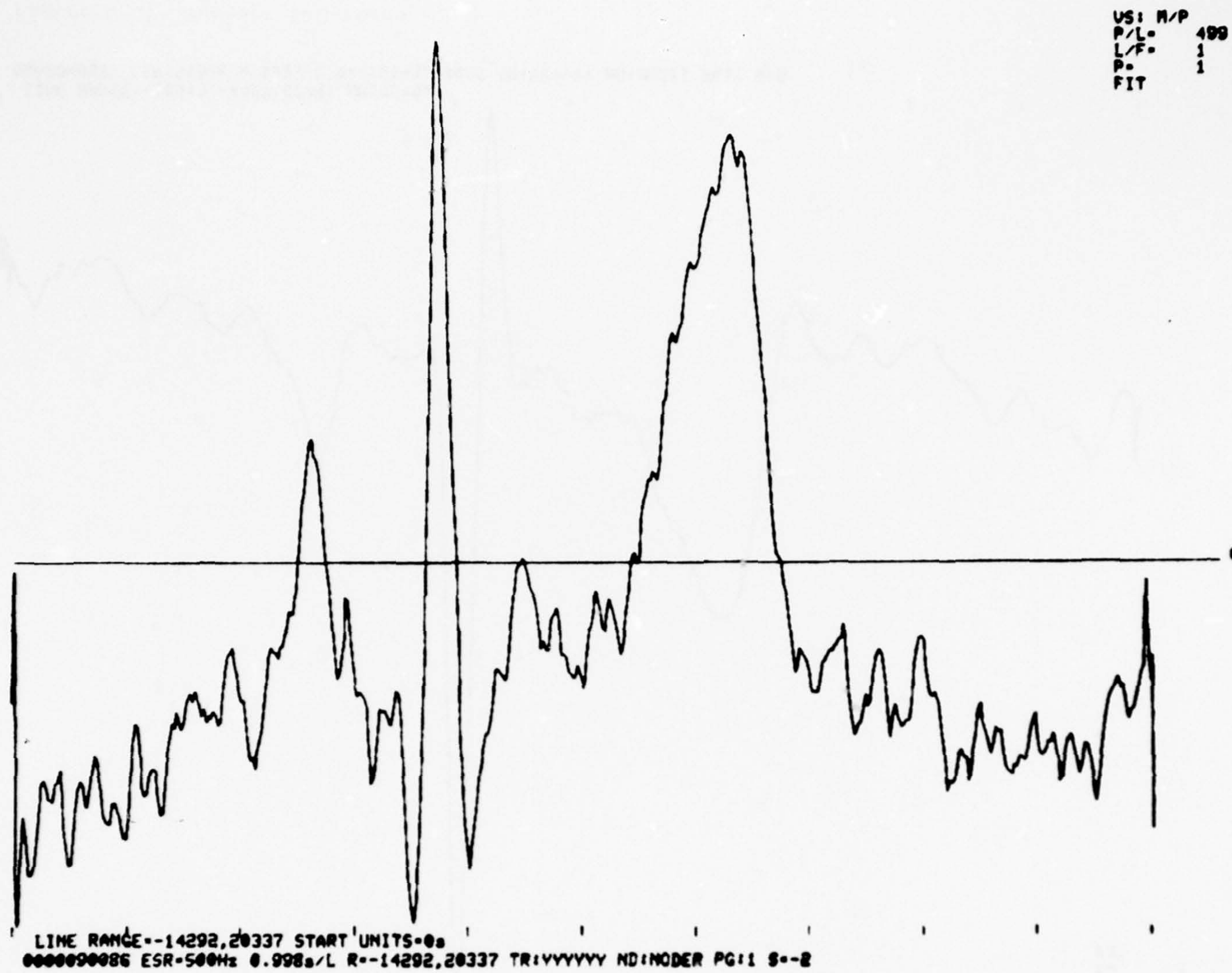

Figure G-18 Subject R C-trace.

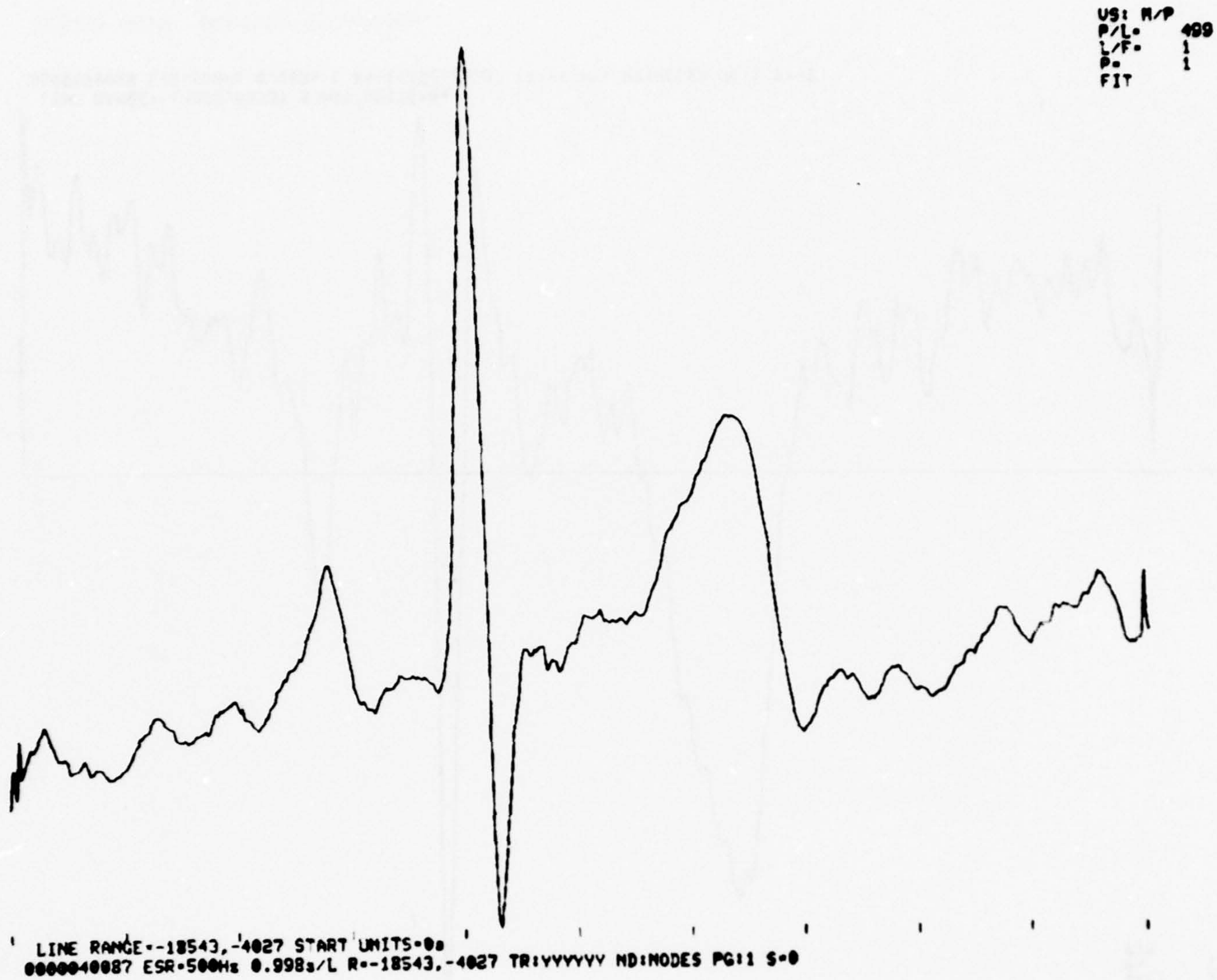

Figure G-19 Subject S C-trace.

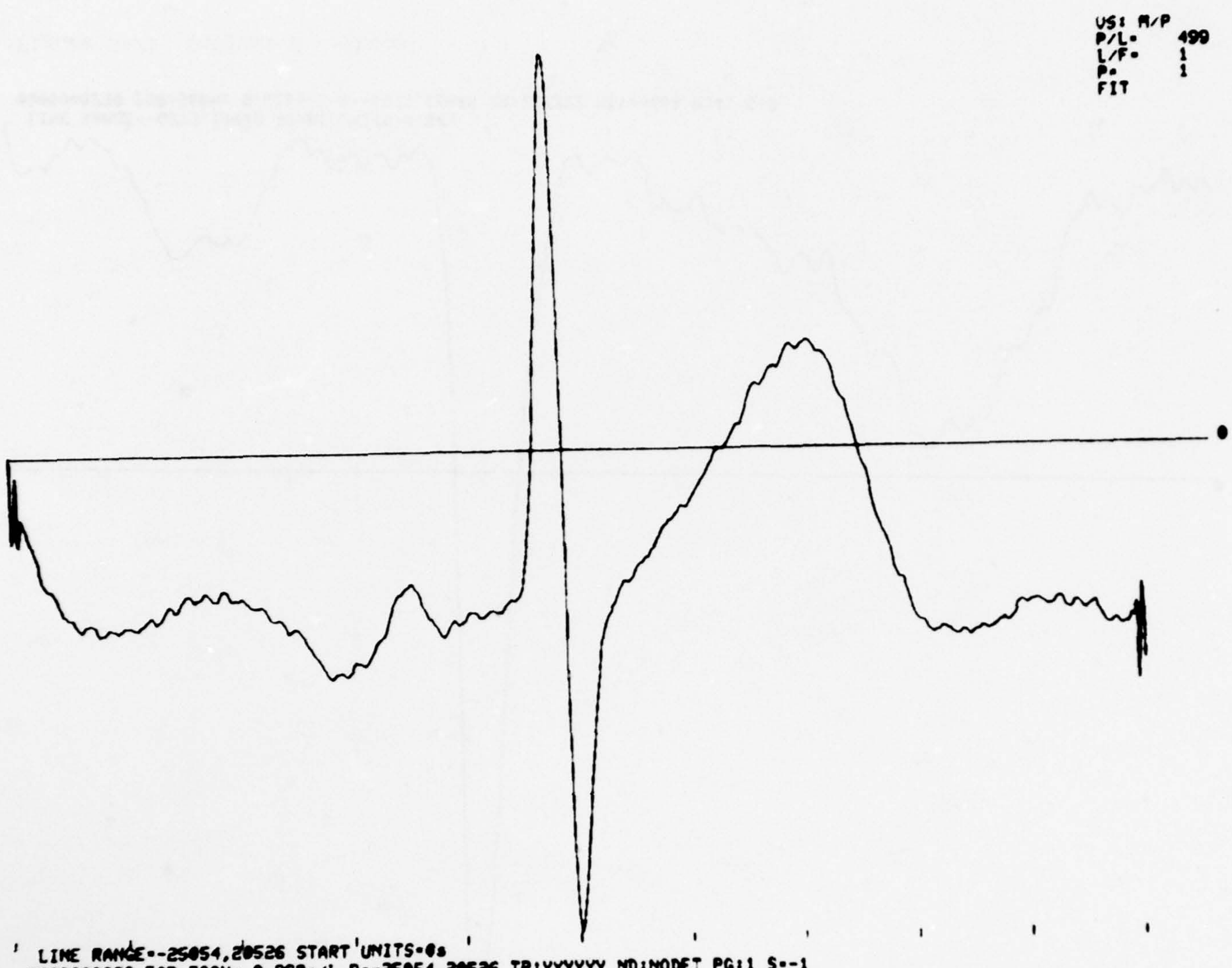

Figure G-20 Subject T C-trace.

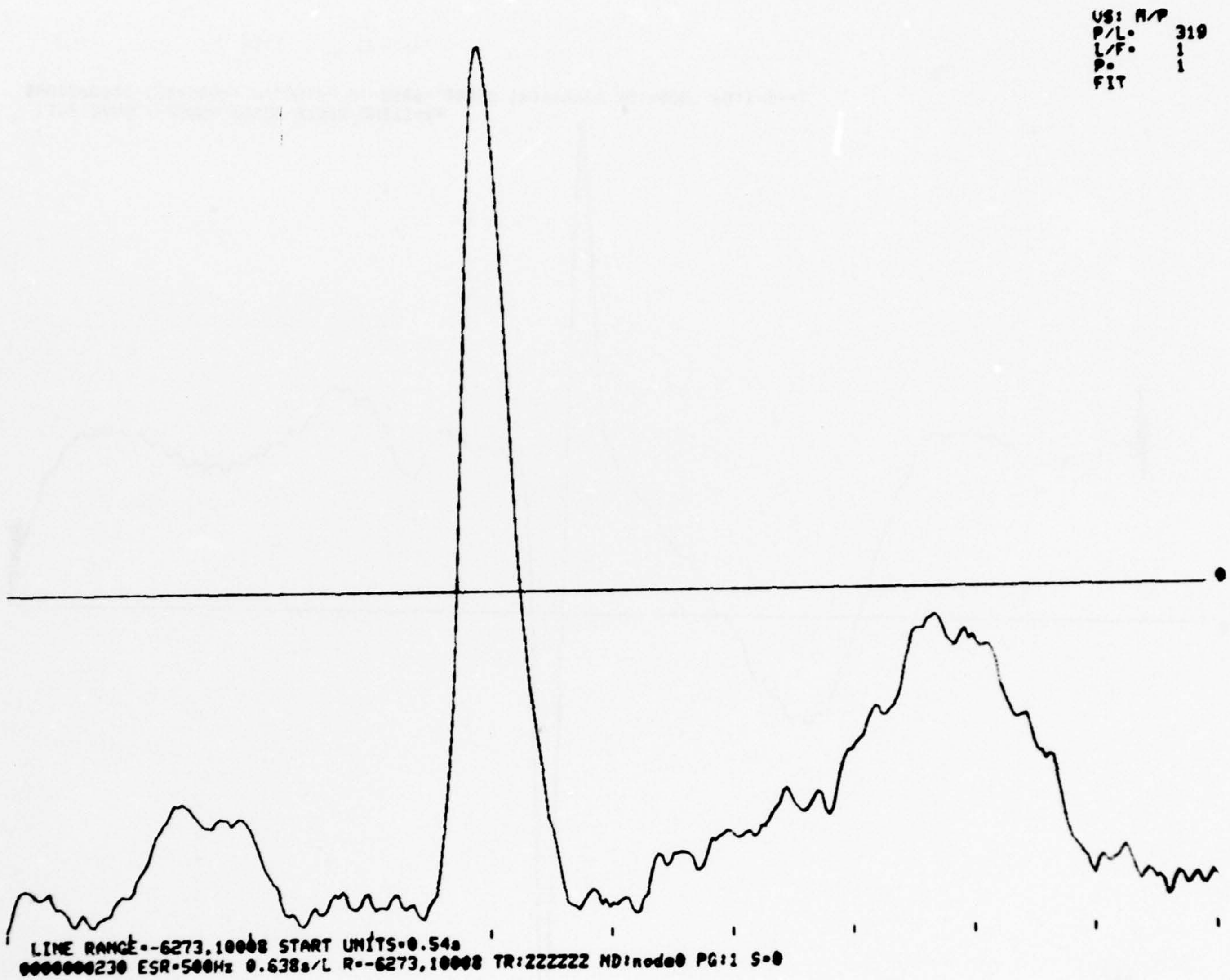

Figure G-21 Subject Ø C-trace.

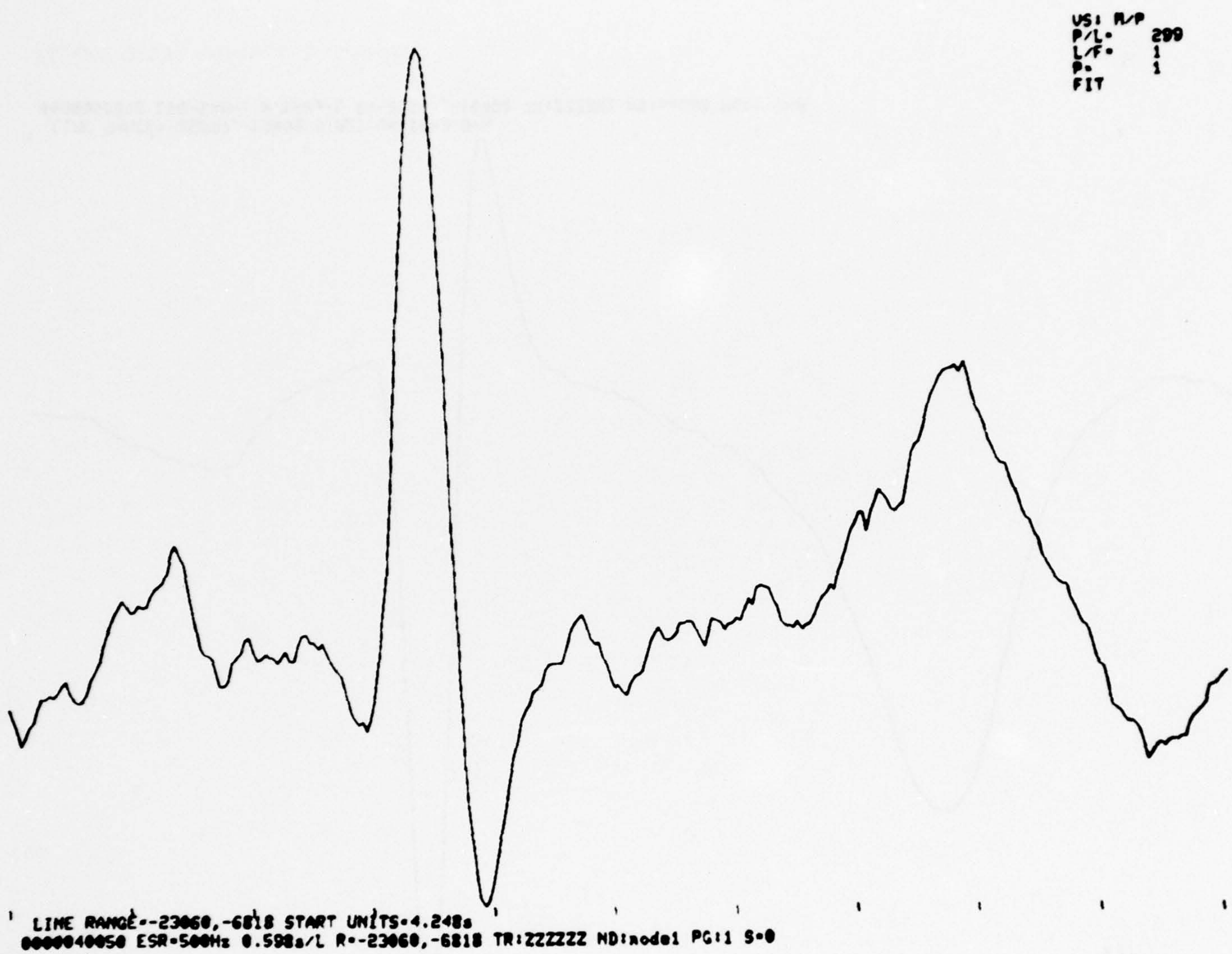

Figure G-22 Subject 1 C-trace.

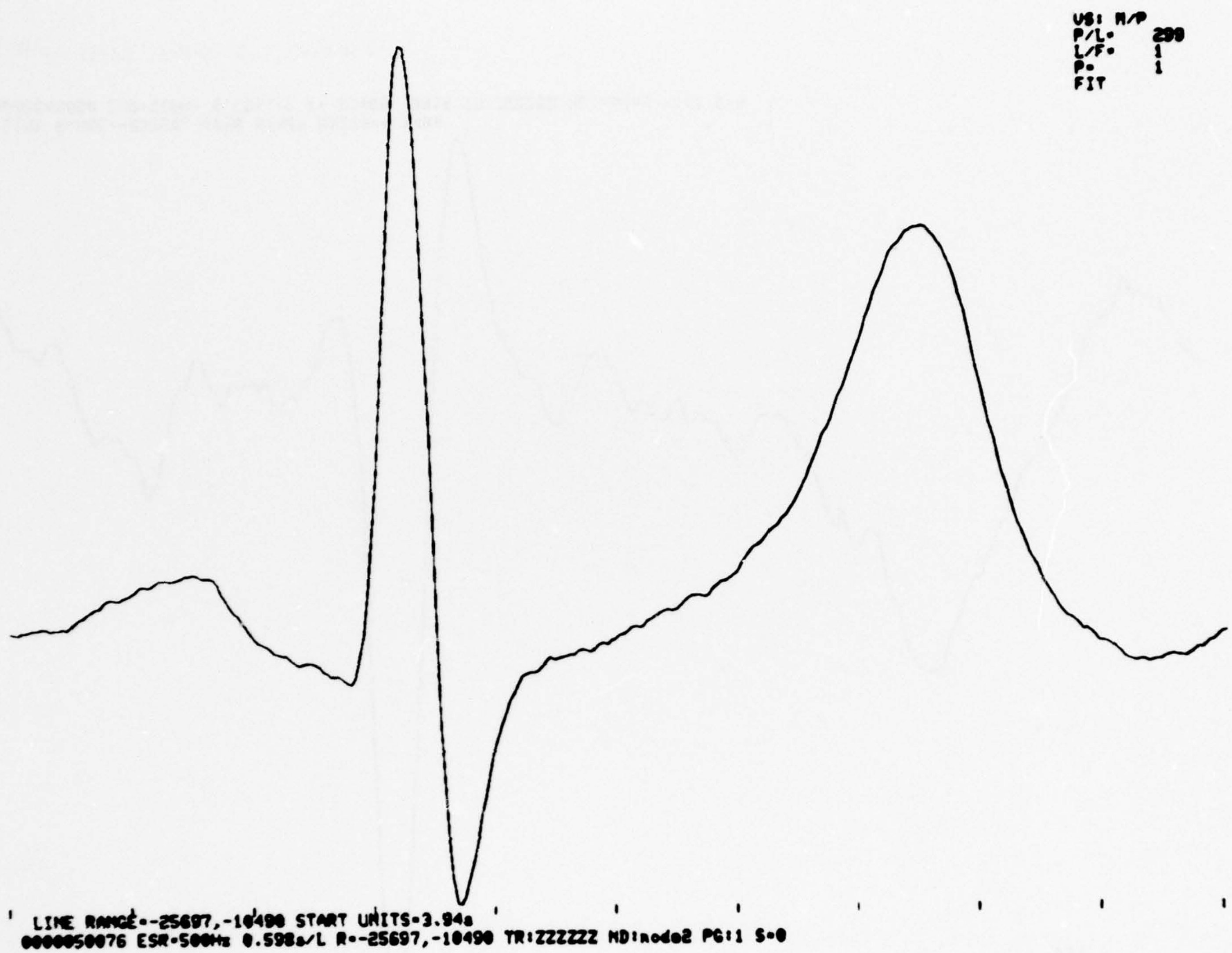

Figure G-23 Subject 2 C-trace.

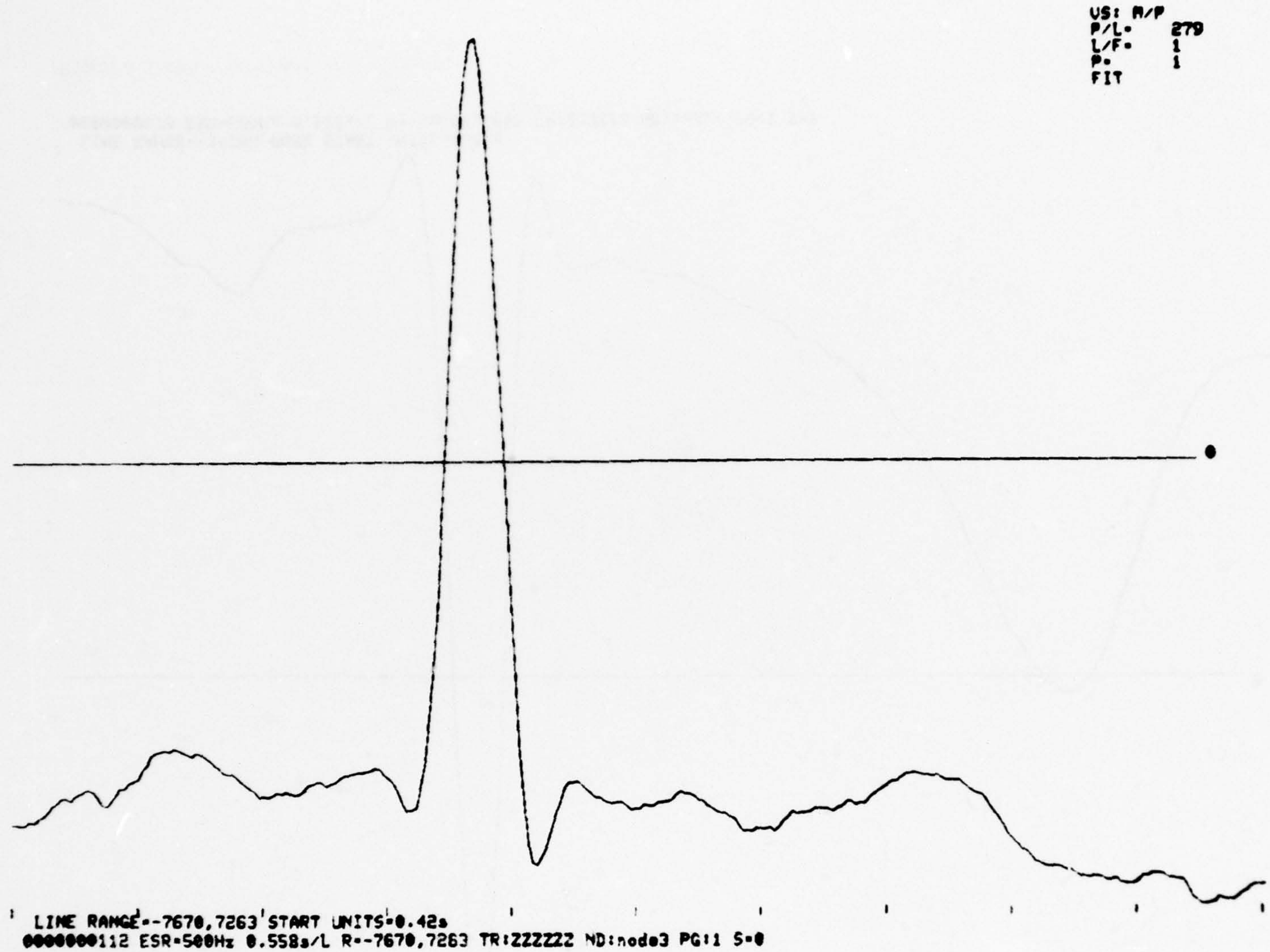

Figure G-24 Subject 3 C-trace.

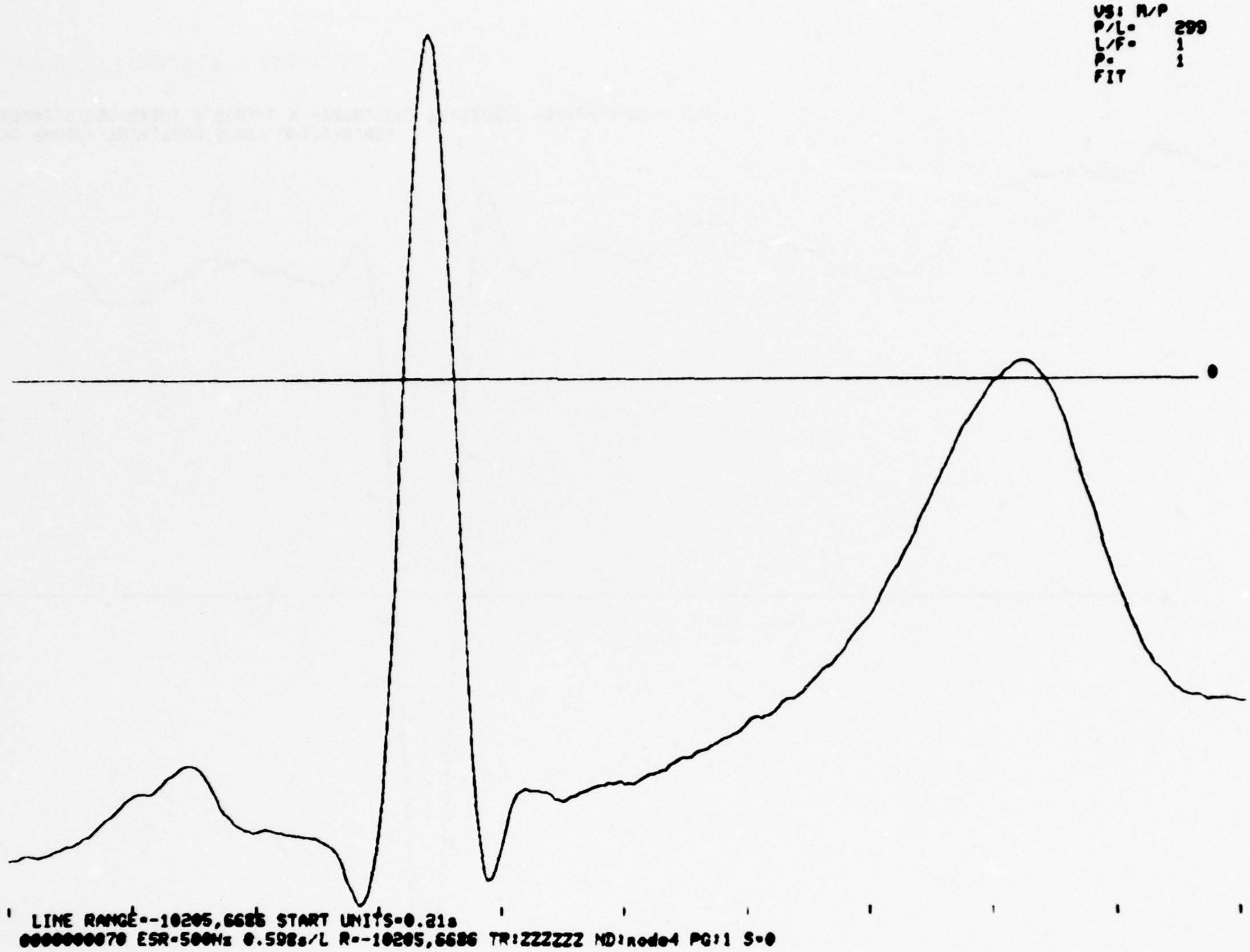

Figure G-25 Subject 4 C-trace.

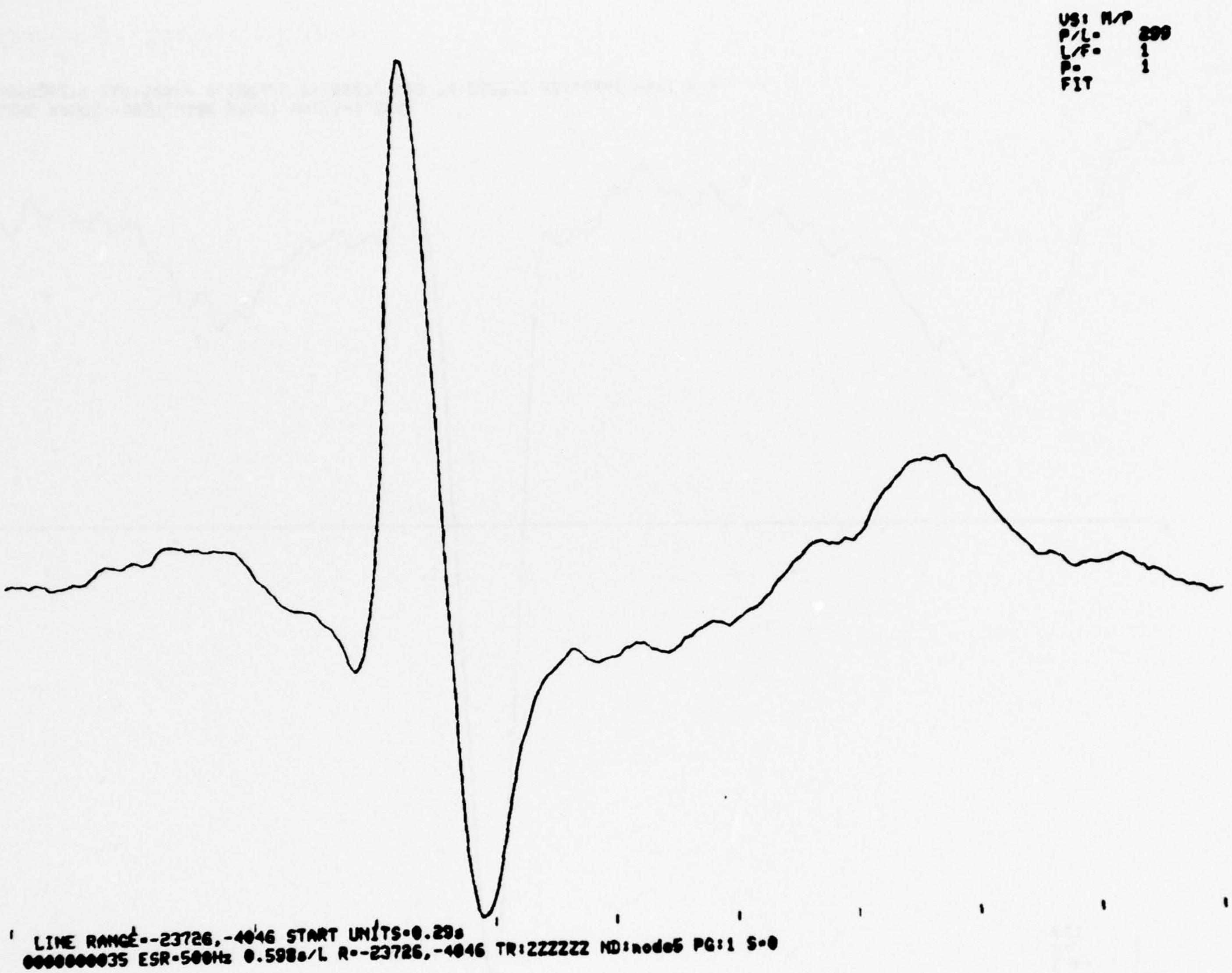

Figure G-26 Subject 5 C-trace.

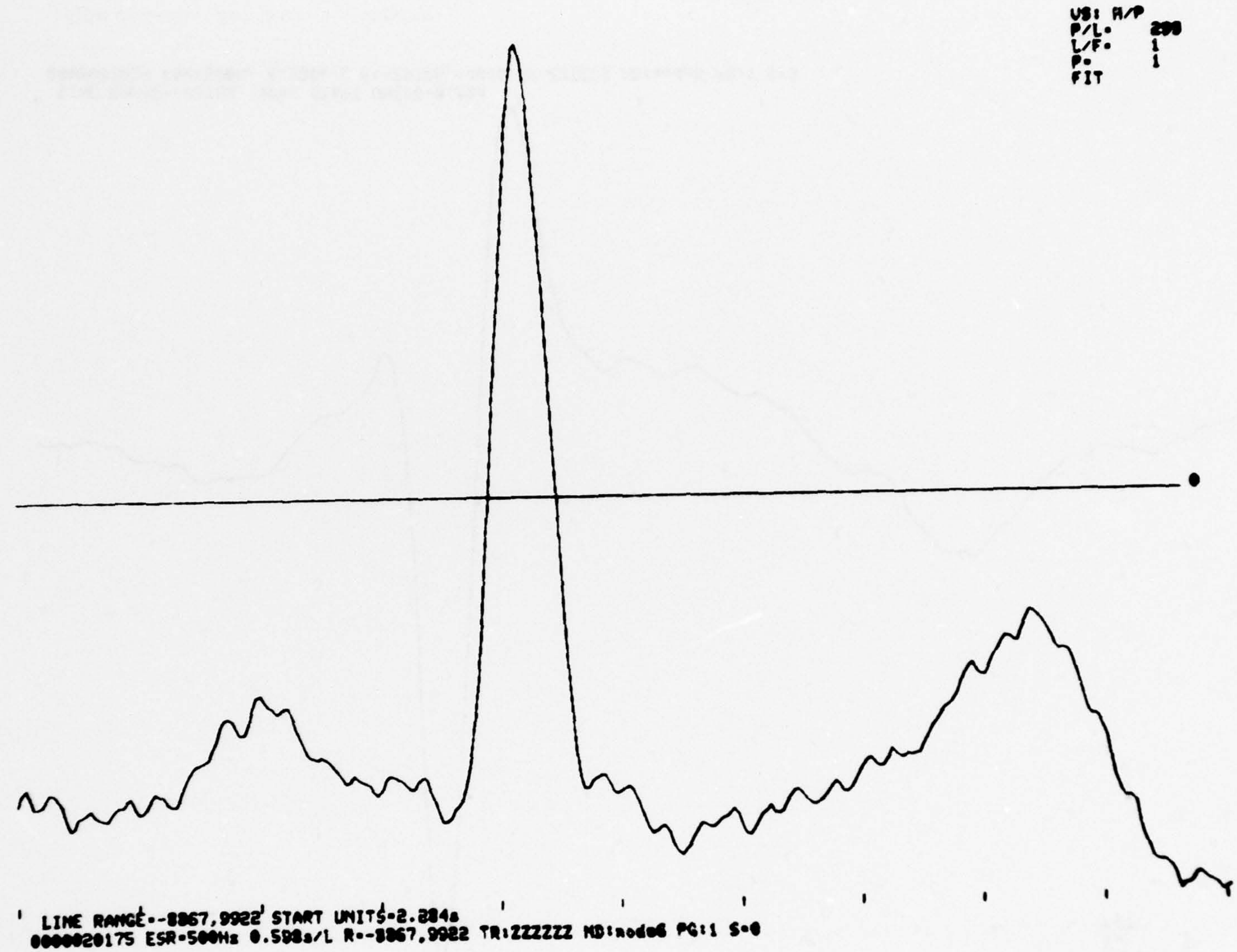

Figure G-27 Subject 6 C-trace.

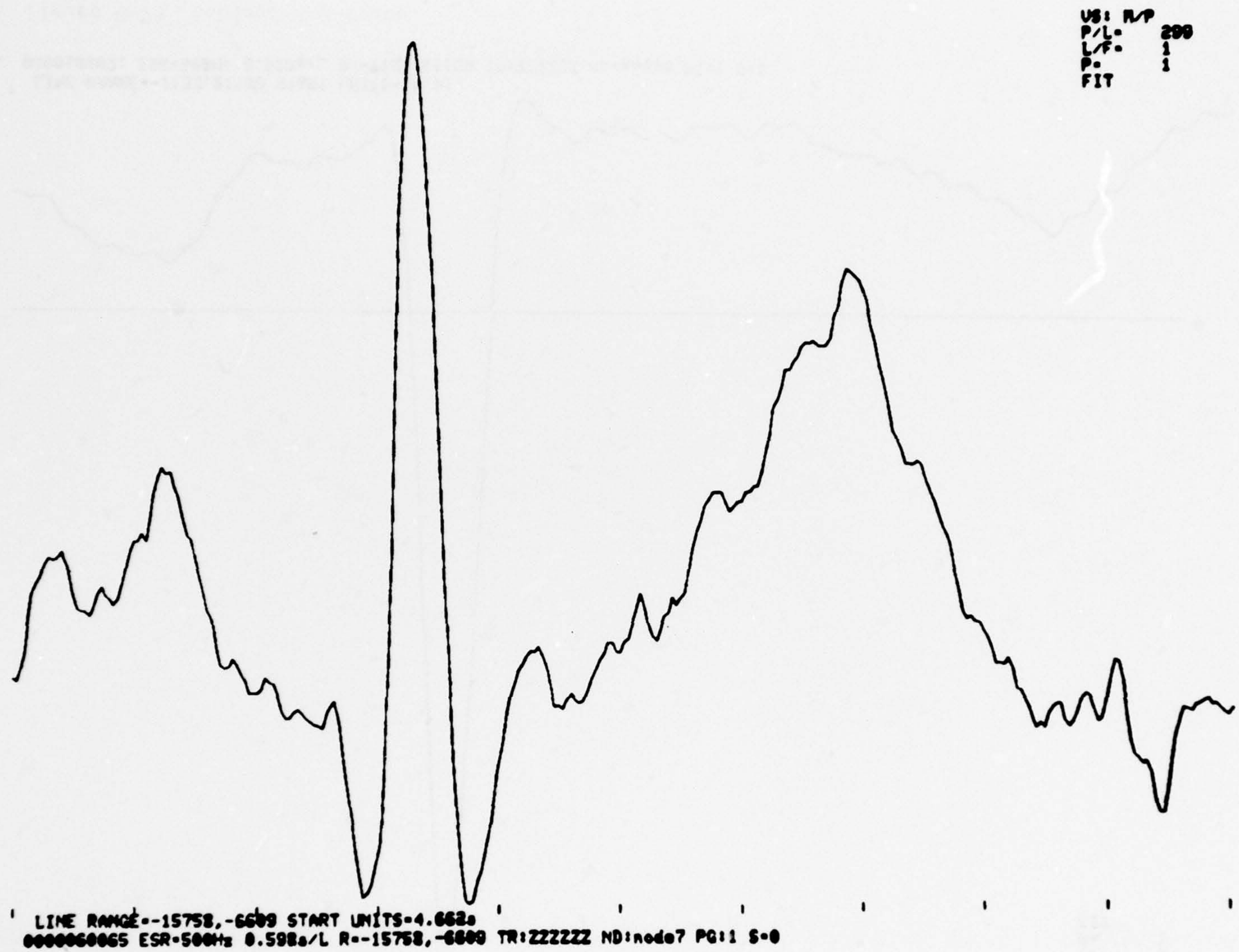

Figure G-28 Subject 7 C-trace.

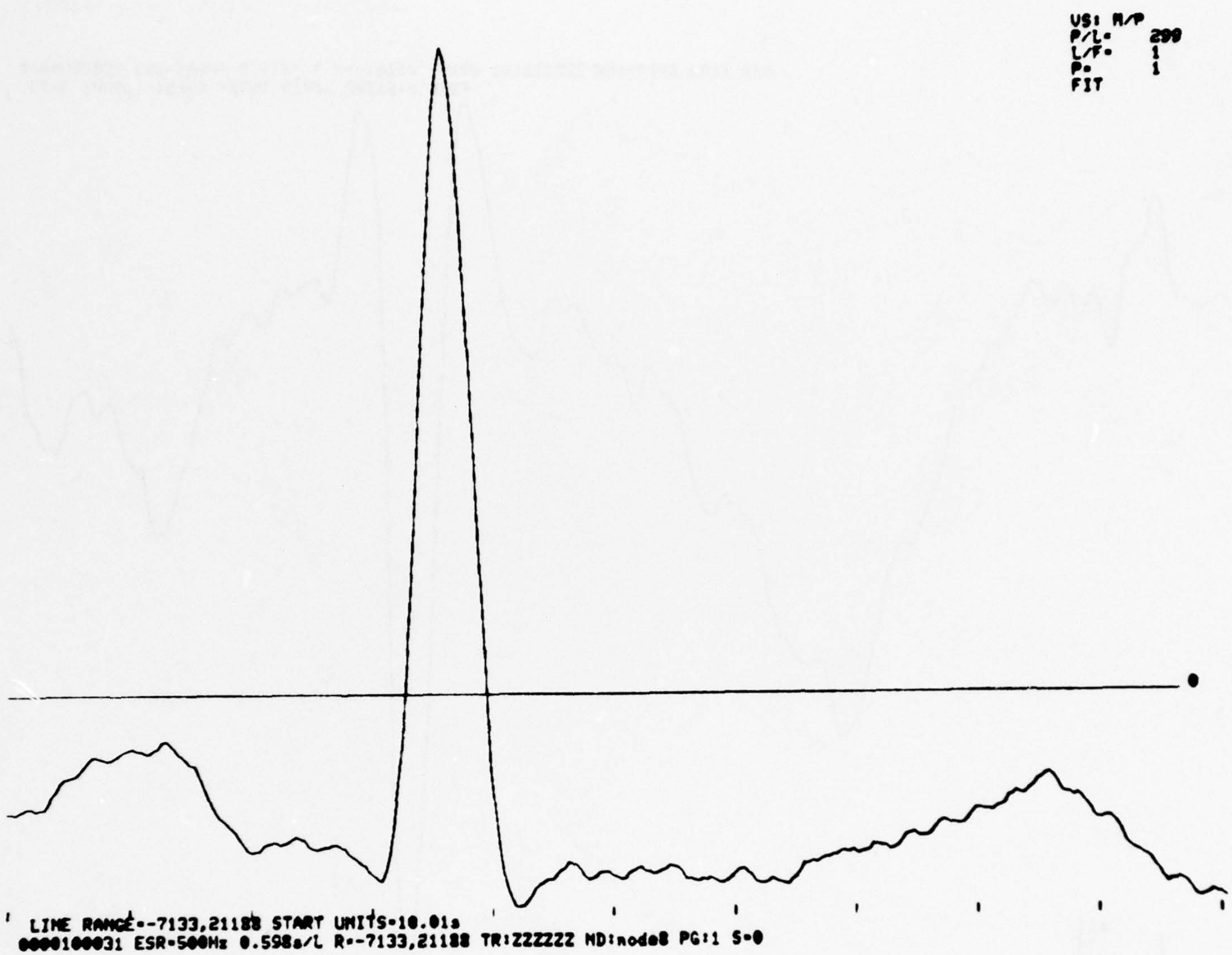

Figure G-29 Subject 8 C-trace.

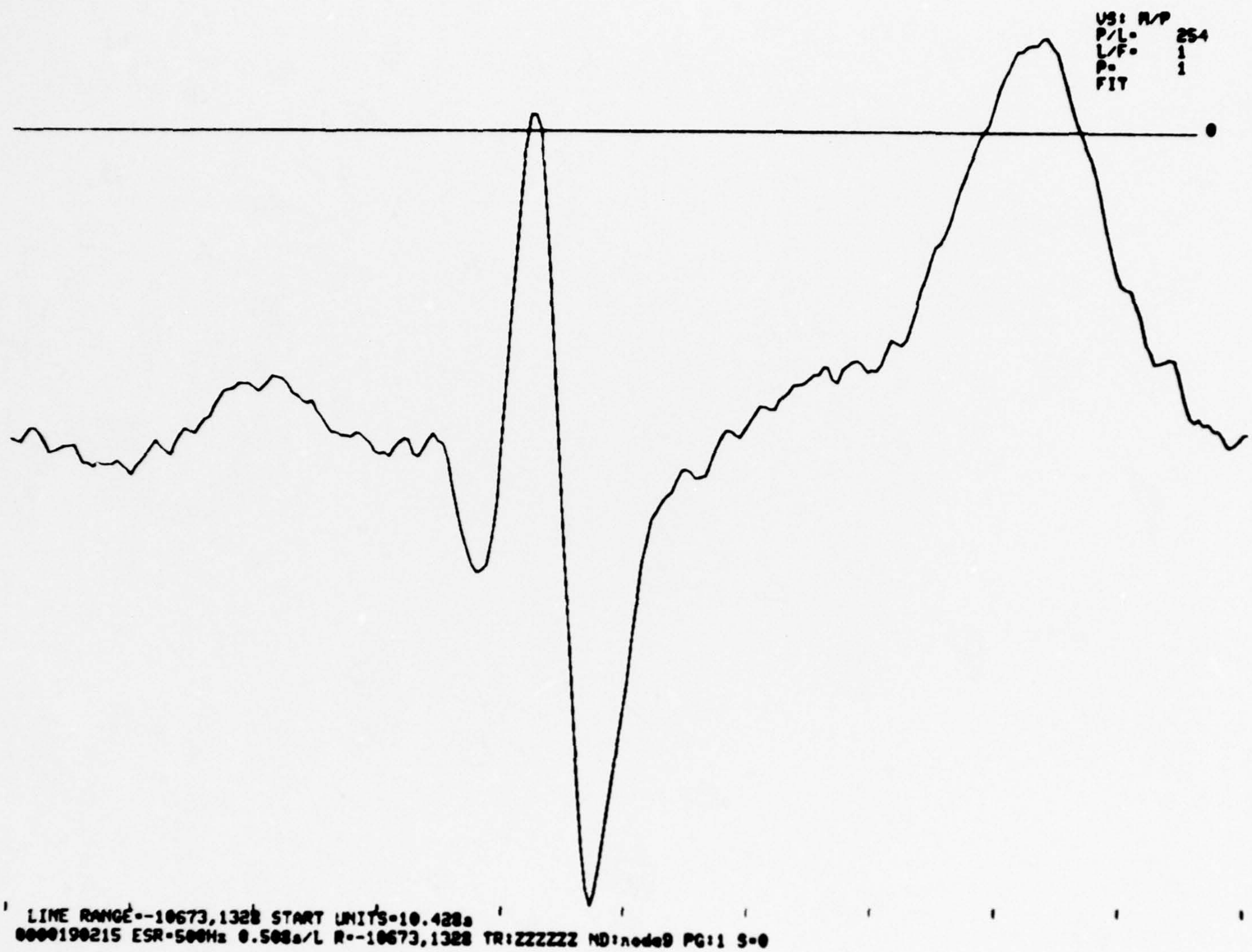

Figure G-30 Subject 9 C-trace.

APPENDIX H

TOWARD AN AUTOMATIC EXTRACTION OF HANDPRINT MEASUREMENTS

Measurements extracted from hand geometry (creases on fingers and palm) indicate significant potential for a solution to the identity verification problem. The bulk of the effort in this area to date has consisted of analysis of hand geometry, selection of candidate descriptors, manual digitization of descriptor measurements, and the design and evaluation of classification logic based on these measurements. Classification logic performance has been excellent as described in subsection 4.1 of this report.

It remains to demonstrate the capability to extract hand geometry measurements efficiently using automatic techniques. During this effort, it was assumed that the most cost-effective approach was to determine the value of the handprint features for automatic personnel verification. This allowed for the evaluation of the potential of hand prints without excessive expenditures for the development of a measurement extraction device, as no off-the-shelf hardware is directly applicable. Although the complete design of fully automatic hardware for handprint feature extraction was outside the scope of this effort, some preliminary investigations have been made as detailed below.

Experimentation was performed using digital processing algorithms available on the RADC Image Processing System (also known as DICIFER).

One subject's fingers were digitized (at 8 bits grey level per pixel) via the on-line Computer Eye vidicon camera and stored as an image file (512 x 512 pixels) on the RPϕ2 disk. Spatial resolution was such that valleys, ridges, and minutiae were visible in the digital image when viewed on the system's TV display. Secondly, the image was processed with a low-pass spatial filter using the "Weighted-Smooth" algorithm on DICIFER. The net effect was a suppression of the "high-frequency" detail of the fine minutiae without obscuring the thicker line structure due to the flexion creases.

The next step was to automatically extract the crease lines and the outside boundaries of the fingers. A picture gradient process was utilized to extract the boundaries. This result was transformed by thresholding to the binary image in Figure H-1. Indications are that with the proper lighting and with firm positioning of the subject hand through the use of a properly designed jig that such a gradient process could be implemented for the automatic extraction of handprint features.

It is recommended that additional processing of handprint data be performed using the RADC Image Processing System in Phase I to determine system design and parameters and in Phase II to implement a test bed verification device.

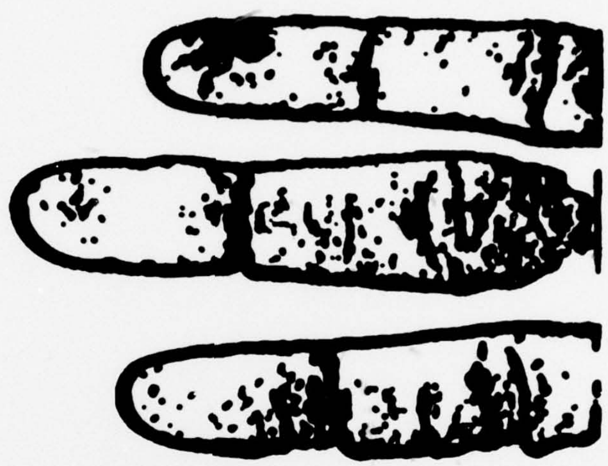

Figure H-1 Digitized and Processed Image of Three Fingers of Right Hand

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